INSTITUTION OF PETROLEUM TECHNOLOGISTS.

The EIGHTY-SEVENTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the Royal Society of Arts, John Street, Adelphi, on Tuesday evening, October 13, 1925, Mr. Arthur W. Eastlake, Vice-President, occupying the chair.

The Chairman, at the opening of the meeting, said he regretted to have to announce that the President, Sir Thomas Holland, was unwell and was unable to take the chair at the meeting; and that, as one of the Senior Vice-Presidents, it was his (Mr. Eastlake's) duty to take his place.

The Secretary read the following list of members elected and transferences made since the last meeting:—

Members.—Alfred William Gustav Bleeck, Jean de Fedorowicz, Ralph Brooks High, John Hubert Hunter, Peter John Manuel Larranaga, Stanislaw Pilat, Francis Heron Rogers, George William Rupert Taylor, Horace John Young.

Transferred to Member.—John Alexander Assheton.

Associate Members.—Carl Norman Andersen, Robert Struthers Forbes, Kenneth Washington Gray, George Heseldin, Frederick A. Hessel, Grahame Russell Johnson, Albert Peter Lieser, Enrique Segala Marcet, Frederick Alan Irving Muntz, Arthur Frederick Cyril Parker, Lewis Reginald Phillips, John Simpson Pirie, Hugh Erfyl Pryce, Harry Norman Swift, Ebenezer Vannan, William George Watkins, Arthur Southwell Whichelow.

Transferred to Associate Members.—Thomas Donald Ambrose, John Horace Blakiston, Oswald Fosbrooke, Walter Glenn Gross, William Ross Sutherland Henderson, Henry Robert Higgins, Thomas Robathan, Frederick Aine Trim.

Students.—Henry Burman, Douglas Alexander Greig, Andrew Cowie Marshall, Hrant Nercessian, Walter Beveridge Rowntree, John Thomas Warde, Francis Erskine Gordon Watson.

Associate.—Duncan Anderson.

The Secretary reminded the members that nominations for the Council must be sent in to him not later than January 31 next. He further announced that the courtesy of the Chemical

Industries Club had been extended to the Dinner Club for the ensuing session. If any members wished to join the Dinner Club for the session they were requested to send in their names, together with 2s. 6d., to Mr. Ashley Carter, Honorary Secretary of the Dinner Club, at 145, Dashwood House.

The Chairman, in introducing the reader of the paper, Mr. Ernest Parsons, said he had done extremely good work on the difficult problem of fixing the stratigraphical relationship of the iron-ore series and the other pre-Cambrian unfossiliferous systems of the Indian peninsula. The Institution was fortunate in being the medium for publishing his independent views of the geological features of Java.

The following paper was then read :—

Notes on the Geology of Java.

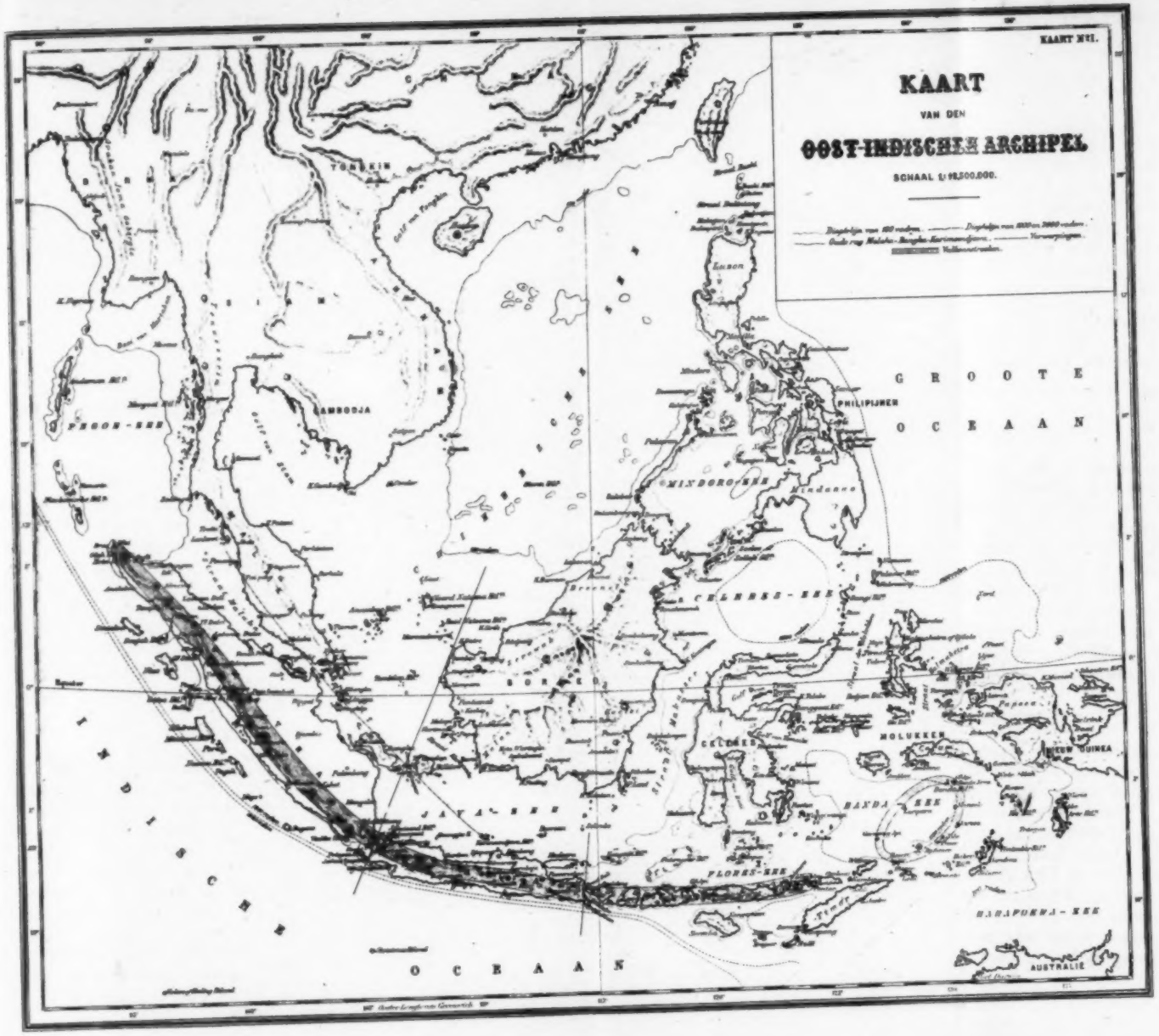
By Ernest Parsons, M.Sc., F.G.S. (Associate Member).

Introduction.

The writer spent a few months last year examining and geologically mapping a large area in Java. The mapping work was done on the scale of 1 : 10,000, and such large scale work revealed important geological relations, not in accord with the views expressed by previous workers in this field. As Java is a recognised source of petroleum, an account of the geology of the country will possibly be of interest to the members of the Institution. A brief geological description of the island as interpreted by previous workers will first be given, followed by a detailed account of the geology of the particular area examined, in order to bring out the points of difference suggested by the recent work.

Situation.

Java is situated in the Dutch East Indies and lies between longitude 105° E. and 115° E., and latitude 5° 50′ S. and 8° 50′ S. It has a length of about 600 miles and a width varying from 20 to 105 miles. The main axis of the island is West and East, and the island forms a part of the great arc of the East Indies Archipelago which extends from Cape Negrais in Burma through the Andaman and Nicobar Isles, Sumatra and Java to Borneo. The more eastern portion of this arc consists of recent volcanoes, which are intruded into and overlie Tertiary formations. The famous Krakatau volcano, which was in violent eruption in 1883, lies on this line midway between Java and Sumatra in the Strait of Sunda.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BANDA-ZEE
FLORES-ZEE
BANDA-ZEE
JAVA-ZEE
AUSTRALIE
G R O O T E
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Topography.

The island is very hilly, the central range frequently rising between 2000–3000 metres (*i.e.*, 7–10,000 ft.). One (the Semeru Volcano) exceeds 12,000 ft. All the peaks of more than 2000 metres above sea-level, and many below that elevation, are post-Tertiary volcanoes. The slope from this highland to the Indian Ocean to the South is very steep, but that to the North to the Java Sea is more gentle. Along the North coast there is an extensive plain, often 15–20 miles in width, and rising very gently to about 100 metres above sea-level.

The central volcanic hills form the watershed, so that the principal streams drain northwards to the Java Sea. The only navigable ones are on this coast and are only navigable a short distance from the coast. Messrs. Fennema and Verbeek have given the following table, which very effectively summarises the question of drainage:—

Drainage.

2·1%	of the area drains to the	West.	
63·3	,,	,,	North.
32·9	,,	,,	South.
1·7	,,	,,	East.

Map No. 1 shows that the steep slope from the central highlands continues southwards to the depths of the Indian Ocean, the ocean deeps being relatively close to the shore. The Java Sea is very shallow. A rise of the land area (or a depression of the sea-level) of 45 metres would establish a land connection between Java, Sumatra, Borneo and Asia. While an uplift of 180 metres would cause the connection of Malay, Cambodia and Siam with these islands.

Climate.

As one would suppose from its geographical position, the climate is tropical, there being little difference between the January and July temperatures, which average about 80° F. It is always humid, especially near the coasts. The rainy season is from about the beginning of November to the end of April, but rains occur throughout the year. The average rainfall at Batavia is about 75″, but at Buitenzorg it is 185″, and is much greater on the higher portions of the central range.

The vegetation is very profuse, and in spite of the density of the population (which is higher than that of England), and the enormous extent of cultivation, one-fifth of the area is forest. The forests are principally of teak or bamboo, those of the latter being almost impenetrable. The terraced hill slopes of Java are a remarkable feature of the island. Owing to the humid climate and dense

foliage, there is a very heavy soil and subsoil and rock exposures are not common. It is therefore important that geological work should be done between May and October, when rainfall is slight and the rivers low.

Maps.

The Netherlands East Indies Government have topographically mapped the whole island, and their maps on the scales of 1 : 10,000; 1 ; 25,000 ; and 1 : 50,000 are excellent. Map No. 2 shown is of the Tji Asem Lands on the 1 : 10,000 scale. These maps proved invaluable in the examination of the area.

Previous Geological Work.

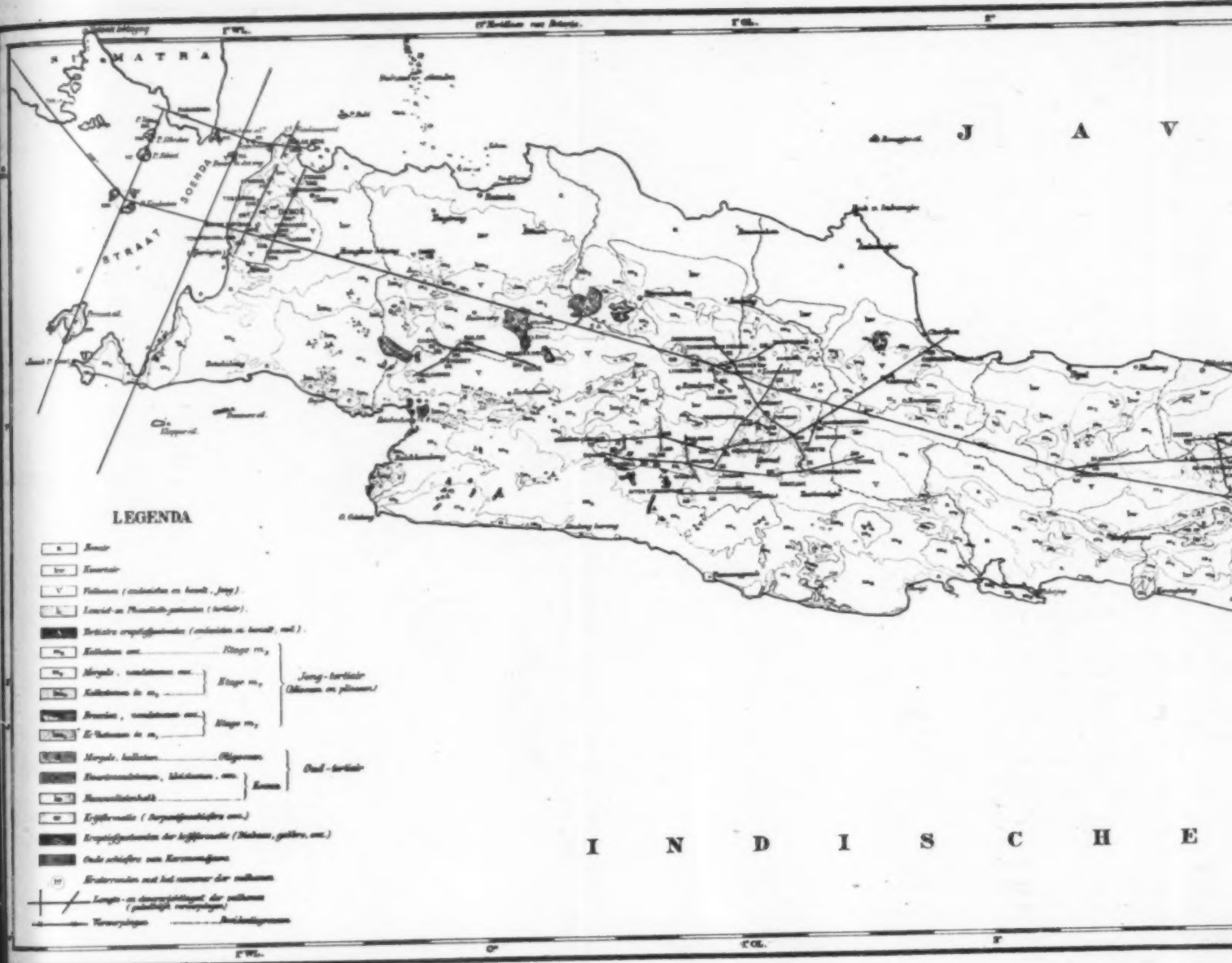
The first comprehensive geological work done in Java was published by Junghuhn in 1855. The standard work, however, is that published in 1896 by Messrs. Fennema and Verbeek, after five or six years' field work undertaken for the Netherlands East Indies Government. Along with this work are published excellent geological maps, sections, etc. This work is a very creditable performance and invaluable to workers on the island. Prof. Martin of Leyden University has also published many paleontological works on the fauna from the Javan rocks.

Geological Sequence.

The following sequence was established by Messrs. Fennema and Verbeek :—

Table No. I.

No.	% age of area.	Strata.	Age.
14	3·470	Post-Tertiary Sediments	Modern.
13		,, ,, with mammal fossils	Modern to Quaternary.
12	27·621	Recent Volcanics	Modern, Quaternary, Pliocene and Miocene.
11	9·807	Calcareous stage (M_3)	Pliocene or Upper Miocene.
10	13·526	Eruptive Rocks	Middle Miocene (upper part probably Pliocene)
9		Clay stage (M_2)	
8	14·419	Eruptive Rocks	
7		Breccia stage (M_1)	Lower Miocene.
6	0·723	Eruptive Rocks	,,
5	0·004	Nanggoelan Beds	Oligocene.
4	0·232	Eruptive Rocks	Eocene.
3		Quartz sandstones with clays and coal.	,,
2	0·152	Serpentinous and Micaceous schists, quartzites, with eruptive rocks	Cretaceous.
1	0·046	Argillaceous schists and quartzites with quartz veins	? ?


SUMATRA
JAVA
STRAAT SOENDA
INDISCHE
LEGENDA

KAART Nº II

GEOLOGISCHE OVERZICHTSKAART

TEVENS

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VAN

JAVA EN MADOERA

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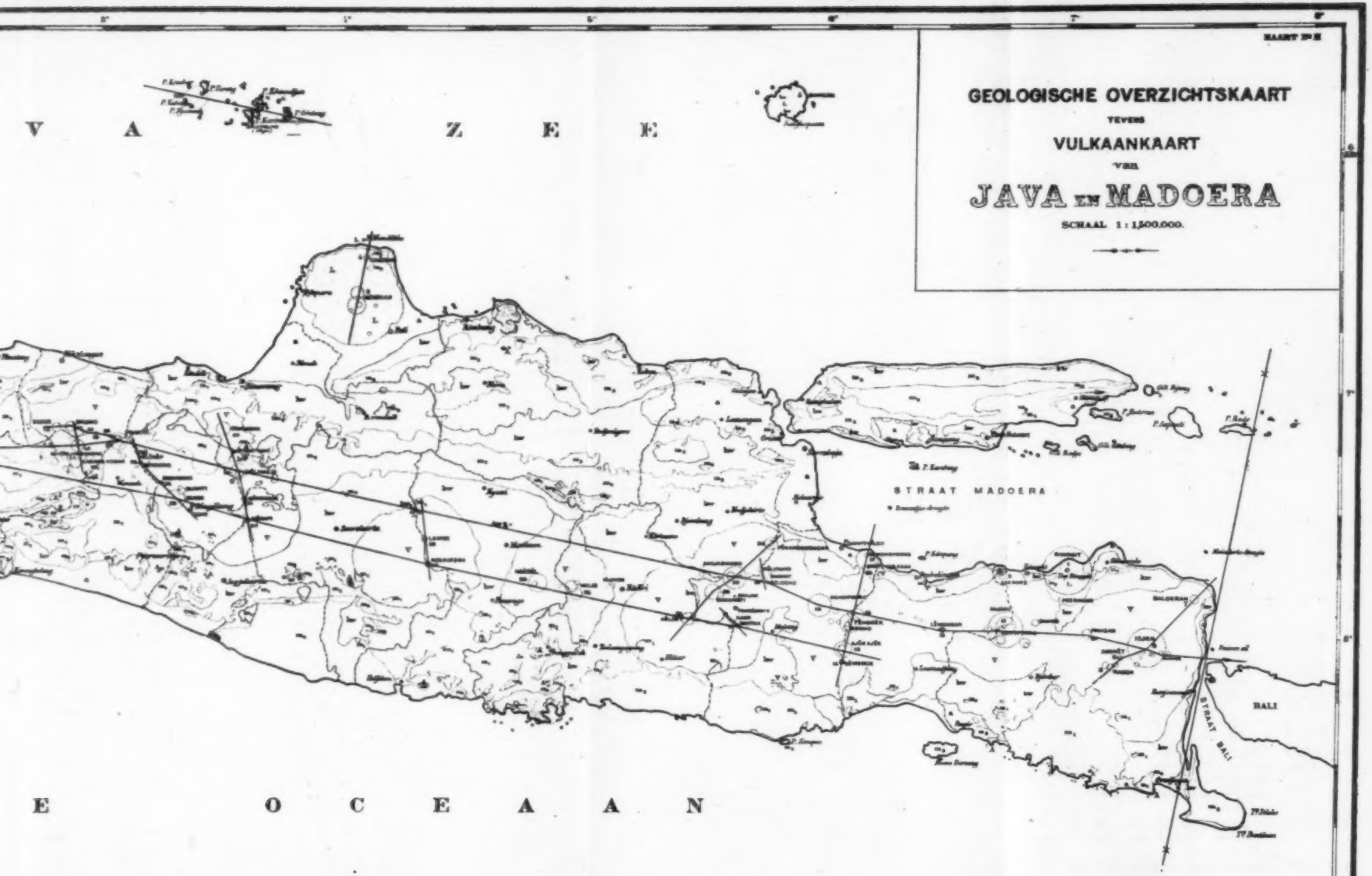

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Junghuhn in his work did not recognise any rocks older than the Tertiary. He regarded the schists as metamorphosed Tertiaries. Further, he grouped all the calcareous beds together. Since his day, the microscopic examination of rock slices has enabled one to identify the foraminifera and so prove beds of Cretaceous, Eocene, Oligocene and Miocene Age.

Description of Rocks.

No. 1. These consist of alternating light and dark grey clay schists and quartzites with quartz stringers. They are not found on the island but occur in the Karimoen Djawa Archipelago. Fennema and Verbeek point out that they are parallel to the longitudinal axis of Sumatra and suppose them to have been brought up to sea-level by the same folds as those traced in Java, and to have provided the floor upon which the Cretaceous and Eocene rocks were deposited. In Sumatra they occur with granite; and several Eocene gravels of Java have been found with granite pebbles.

No. 2. These comprise sedimentary and eruptive rocks. The latter consist of diabase, gabbro and quartz porphyry. The two former occur in beds conformable to and alternating with the sedimentaries. The relation of the quartz porphyry is unknown. The sedimentaries are represented by serpentinous, chloritic, talc, and micaceous schists, and sandstones of green colour and some crystalline limestones. The latter are usually unfossiliferous, but in Banjoemas have yielded Orbitolinæ. The sandstones are regarded as volcanic ashes and tuffs by Fennema and Verbeek. These rocks are thought to be the equivalent of some beds found in Borneo, where an Upper Cretaceous molluscan fauna has been found. The beds are highly folded and no estimate of thickness can be made. They are overlain unconformably by newer rocks, and are only found in three localities.

No. 3. The Eocene beds consist largely of very pure quartz sandstones. This is characteristic of this group of rocks in Borneo and Sumatra also. Two divisions are recognised, an upper one (E_2) which consists of sandstones alternating with conglomerates, grey and carbonaceous shales and coals. These are of freshwater origin. The earlier stage (E_1) is mainly of sandstone and of marine origin. The two stages are only found together in one locality, namely, Tji Letoe Bay. The beds are usually considerably disturbed, and unconformable to both over and underlying formations. The calcareous beds have yielded fossils. In one locality with the interbedded eruptive rocks they attain a thickness of 1000 metres.

No. 4. Interbedded with the Eocene are a series of gabbros and

diabases. These are always conformable to the Eocene sedimentaries. They are similar to the rocks of group 2.

No. 5. These beds occur on the boundary of the Beguelen and Banjoemas Residencies, and have yielded a distinctive fauna. They attain a thickness of between 150-250 metres and consist of sandstones, clays, and a few calcareous beds. Equivalent beds have been found in other localities but are rarely more than 10-20 metres thick. This has proved an important paleontological horizon.

No. 6. In a few localities some eruptive rocks are found at the base of the Miocene formation. They are generally andesitic in character, except in Bantam where they may be of Eocene age, and are of diabasic character. Messrs. Fennema and Verbeek think that at the close of the Oligocene period there was considerable volcanic activity, which was of the fissure type.

Nos. 7-11. The volcanic beds at the base of the Miocene formation were deposited partly above and partly below sea-level, and consequently they alternate with water deposited breccias, sandstones, clayey sandstones and clays. The stratification is seen often only with difficulty. This group is of Miocene age and is classified by the above writers as :—

3. Calcareous stage (M_3)
2. Clay stage (M_2)
1. Breccia stage (M_1)

No. 1 being the oldest. Fossils are found in the upper portion of the clay group, and in the calcareous beds. None are known from the breccia stage. In some localities the two upper groups are probably of the same age.

Breccia Group.—As the name implies, this group consists largely of igneous breccias, both water deposited and also deposited under terrestial conditions. Interbedded with the breccias are lavas, conglomerates, sandstones and sandy clays. The thickness is very variable.

Clay Group.—This consists mainly of grey clays, often indurated and partly cleaved. In the upper portions they alternate with sandy clays and sandstones and some beds of lignitic coal. They are estimated by Messrs. Fennema and Verbeek as of 150-300 metres thickness, but attain quite 2,000 metres in Cheribon.

Calcareous Group.—This consists chiefly of thinly bedded limestones with calcareous clays and an occasional gravel bed. In Rembang, clays and loams are interbedded with the calcareous clays. The principal Miocene fossils are derived from this group.

No. 12. At the close of the Tertiary period, there was a renewal of igneous activity and volcanic outpourings took place on an

extensive scale. This vulcanicity was accompanied by considerable earth-movement, which undoubtedly had begun in Tertiary times. This volcanic activity has continued until to-day, and there are now no fewer than sixteen active volcanoes, and many more in the solfataric stage. Krakatau was quiescent from 1680-1883 A.D., and it is not unlikely that some of those volcanoes now regarded as extinct may again burst forth into eruption. Messrs. Fennema and Verbeek point out that the volcanoes may be grouped along certain lines, one parallel to the South coast and others at right angles thereto. These lines they regard as zones of fracture. The rocks of this group are either andesitic or basaltic in character, in contrast to the diabasic character of the earlier eruptives. A group of volcanoes around Ringgit yielded formerly phonolitic and leucitic rocks, but later eruptions of these have given andesitic eruptives. The recent volcanoes are developed principally along the central range of the island.

No. 13. The Quaternary period was one of volcanic outburst, consequently the sedimentaries of this age consist of detrital material from the weathering of the volcanoes and lavas. They are usually in a finely divided state and clayey. They are water deposited, and rarely at a higher elevation than 100 metres. They are distinguished from the recent deposits by the fact that the soils derived from the weathering of these beds are of a rich brown colour, whereas the latter are grey. In addition to the coastal deposits of this age Fennema and Verbeek recognise a few interior lake deposits of this period. These lakes were either formed by the volcanic debris interfering with the drainage channels, or by earth-movement (most probably the former). The coastal deposits are divided as follows:—

3. Horizontal freshwater deposits.
2. Marine clays and sandy clays.
1. Horizontal or slightly inclined freshwater deposits.

Nos. 13 and 14. These consists of marine coastal deposits, river alluvium, coralline deposits off the coast of Bantam, tufaceous deposits around hot springs, etc. Ninety per cent. of the materials of these rocks are volcanic and are rarely found more than ten metres above sea-level.

Paleontology.

Considerable work has been done on the faunas of the Javan Tertiary rocks, especially by Prof. Martin of Leyden University. The calcareous beds of several ages have yielded an extensive foraminiferal fauna. The Miocene and Oligocene beds have furnished both molluscan and foraminiferal faunas. Unfortunately most of

the Miocene fossils are from the upper group. A few turritellae and Coni have been found in the clay group, but from one horizon only. The breccias have not yielded fossils. Owing to the vertical distribution of the fossils, the paleontological evidence is not of much assistance in the subdivision of the Miocene series. Prof. Martin has pointed out that "the determination of the age of the Javan Tertiary deposits is beset with great difficulties, owing to :—

1. The great difference between the Javan and European Tertiary faunas.
2. The absence of climatic variations, which had a great influence on the European fauna.
3. The incomplete paleontological knowledge of the East Indies and British India faunas.

The first is due to the fact that the Pacific and the Atlantic Seas, which were connected during early Tertiary times by the Tethys Sea, became separated in late Eocene or early Oligocene times (probably by the uplift of the Himalayan Range). The second has resulted in the persistence of early Tertiary forms to a much later date in the Javan area than is found in the European area. Owing to the third there is no basis of comparison of these two areas.

The result of the separation of the Atlantic and Pacific Seas has been that the influx of new species in the Javan area is less common than in the European area, and the zonal range of the species differs. Prof. Martin asserts that "In the study of the vertical distribution of Nummilinae, the facies of the deposits is too much neglected, and this is particularly true since it is established that these animals react with unusual rapidity to changes of environment, without reference to their general occurrence. At all events one must be cautioned that the older Miocene of the Indies on the basis of the foraminifera, according to European time scale, may be divided into Aquitanian and Burdigalian. Furthermore even the molluscs furnish no certain criteria."

Prof. Martin has attempted an age estimate on the basis of the percentage of living species, and places a higher value on such a comparison than on the comparison with the foraminifera of Europe. The difficulties of an attempt to classify on such a basis need no emphasis. Prof. Martin places considerable stress on the importance of a careful study of the stratigraphy for the age determination. A worker in Java (Kemmerling) has gone so far as to say that it is impossible on paleontological grounds to determine the age of the Java Miocene beds, as these are characterised by "inconstant strata."

Enough has been said to show that while the Miocene age of the Javan rocks can be definitely asserted, it is impossible at present

to group them under the present European subdivisions. As an example of this Prof. Martin points out that from a consideration of the Nummulinae of the Nanggoellan Beds, no decision could be reached as to whether the beds should be referred to the Lutetian or to the Upper Eocene, which latter age can be deduced from the molluscan fauna. Again in the case of the Rembang and the West Progo beds, the latter possess a far smaller percentage of living species than the former, but if a conclusion be based on the foraminiferal evidence, the latter could not be older than the uppermost Aquitanian or even Burdigalian, while the former probably belong to the Middle Aquitanian. Judged from the molluscan fauna the West Progo beds must be referred to the older Aquitanian.

It is clear, therefore, that one must rely on the stratigraphical evidence in the determination of relative age, until a zonal scheme has been worked out for the East Indies by the paleontologists.

Distribution of Rocks.

Before studying the special area examined by the writer it will perhaps be advisable to notice the distribution of the various groups recognised above.

Cretaceous.—These are the oldest rocks outcropping on the mainland, and outcrop in three localities :—

(*a*) S. of Tji Letoe Bay.
(*b*) On the Beguelen and Banjoemas boundary.
(*c*) In the chain of hills near Djiwo (Solo).

Eocene.—These have a more extended outcrop than the above, and occur at :—

(*a*) The Baiah coal area.
(*b*) S. of Tji Letoe Bay.
(*c*) Near Soekaboemi and in the Tji Mandiri valley.
(*d*) In Beguelen.
(*e*) A small outcrop S.W. Kedoe.
(*f*) In the Djiwo hills.

Oligocene.—These have a very limited outcrop.

(*a*) Near Nanggoellan.
(*b*) In the Tji Sokan near Radjamandala.
(*c*) In Beguelen.

Miocene.—Have a very extended outcrop from the Strait of Sunda to that of Bali in the East, and across almost the entire width of the island, except where they are covered by the quaternary and recent volcanics.

The Breccia Group is confined to the centre of the island. The water deposited beds of this group are not found higher than about 1,200 metres above sea-level.

The Clay Group is generally speaking North and South of the above rocks. Its greatest extent is in Cheribon, Krawang and Batavia, where it most probably is also the equivalent of the later group. Its maximum altitude is about 1,200 metre above sea-level.

The Calcareous Group is absent in the centre of the island, and in the West of Java except along the South coast. Its most extensive development is in East Java, South and East of Semerang. The maximum uplift of rocks of this group is on the Jogja and Beguelen boundary, where they attain an elevation of about 900 metres.

Quaternary.—Except for the lacustrine deposits of the three great plains of Bandoeng, Garoet and Somedang, these rocks are confined to the North and South coasts.

The Geology of the Tji Asem Lands.

These lands comprise portions of the central range, the Miocene Hills and the Quaternary and recent plains along a stretch of the North coast. They lie in the Residency of Krawang. The drainage of the lands is from South to North, the principal rivers being the Tji Asem, the Tji Lamaja, and the Tji Poenagara with its tributary the Tji Lamatan.

The writer has classified the rocks outcropping in these lands as follows:—

5. Recent.
4. Quaternary sediments.
3. Volcanic series
   (*a*) Recent.
   (*b*) Older (of Quaternary to Pliocene Age).
2. Breccia Series.
1. Grey Clay Shale Group.

No. 1 is the oldest and consists largely of grey clay shales. It is a very fine clay deposit, which has become indurated and in some cases cleaved by pressure of superincumbent rocks and earth-movement. Bedding planes are not well defined, and it is often difficult with the limited and weathered exposures to determine the lie of the strata. The clays are remarkably constant in composition, but occasional ironstone nodular inclusions occur. The lower horizons particularly are very constant, the only rock other than clay being occasional igneous intrusions. The upper beds become more sandy, and sandstones and clayey grits are

found. A few carbonaceous shales occur high up in the group and occasional plant remains are seen. At this horizon fossils are abundant, being represented mainly by a turritella and other gastropods. Inclusions of cherty nodules are occasionally found and in one or two cases were proved to be silicified wood.

The beds have an East and West strike, and occupy a strip of country forming the foot hills to the Miocene hills. In the western portion of the area, they are very disturbed. The strike swings round almost to North and South and the dips approach the vertical. There is no doubt this is the M_2 group of Messrs. Fennema and Verbeek. In these Lands there are no representatives of the calcareous group, which are probably of the same age as the upper beds of the clay shale group. (The local lime for building purposes is obtained from the tufaceous deposits around the hot springs.)

The breccia group comprises both sedimentary and volcanic beds. The group is so named as breccia beds predominate. These breccias are undoubtedly of volcanic origin, and consist of boulders of several types of igneous rocks, the principal being andesites and basalts. The matrix of the breccia consists of decomposed lava. Some of the beds have been deposited under water as shown by some degree of sorting and bedding, but many of them are of terrestial origin. In the western portion of the Lands, the breccias are neither so common nor so coarse as in the eastern; here lavas and possibly intrusives are more common. Lavas occur throughout the group, but owing to their weathered condition and the fact that the sedimentaries are derived from the erosion of the same rocks, it is often impossible to decide which are igneous and which detrital in origin. The sedimentaries are represented principally by grey clay shale (similar to that of the lower formation), sandy clay shales, clayey grits and some carbonaceous shales. Brown coals are found in the upper parts of the group. The basal beds are undoubtedly transitional with those of the grey clay shale group, and it is difficult to know where to place the boundary. The sedimentary beds higher in the formation consist of coarser sandstones and conglomerates with some carbonaceous shales and coals. Some of these were undoubtedly deposited in very shallow water where little, if any, sorting action could take place. The lower sedimentary beds frequently contain fossils identical with those of the upper beds of the clay group. Fossil wood is found throughout the group, and in the upper Tji Baroeboes valley an occurrence of petroleum jelly was noted.

The group, although shown on the map outcropping over a very limited area, underlies a very considerable portion of the Lands. The river erosion discloses these beds throughout an East and West belt South of that occupied by the shale group, and under-

lying the volcanic series. This is undoubtedly the M_1 group of Messrs. Fennema and Verbeek.

The *Volcanic Series* falls naturally into two divisions, one considerably older than the other. The earlier group is characterised by lavas with porphyritic felspar crystals in a hemi- or non-crystalline groundmass. They give rise to red, yellow, grey and white soils. This older group is found extensively developed in the extreme south-east of the area examined, north of the outcrop of the recent volcanics. The series consist almost entirely of lavas, but a few breccias occur. The latter differ from those of the breccia group in that they contain much smaller boulders and have a larger percentage of matrix which renders them more clayey. The majority of these beds were deposited on a land surface. They appear in some instances to be conformable with the upper beds of the breccia group, but usually lie across the weathered edges of this group. The later division of the volcanics are of relatively recent date, and are undoubtedly younger than the Quaternary deposits. They were deposited after the faulting took place, whereas the older group are affected by the faults. At the time of their ejection and deposition the Lands had been raised and had developed a topography not dissimilar to that of to-day. These recent volcanics cover a very extensive area. They are characterised by dark grey to black basaltic lavas, which are frequently massive and vesicular. The lavas have broken down to a dark reddish brown soil containing boulders of the vesicular lavas. This is well seen at the Tji Nangka bridge and on the Kassomalong and Sariredja Estates.

Near the source (G. Tangkoeban Prahoe) this group also contains coarse breccias, which are entirely igneous. They are exposed in the Tji Poenagara valley S.E. of Sariredja and in the Tji Moedjha North of Panaroeban.

Quaternary Series.—Messrs. Fennema and Verbeek have mapped the detrital deposits north of the outcrop of the grey shale as Quaternary. The writer is of opinion that these might better be classified with the volcanics, as they contain lavas, and all the sedimentary beds are of volcanic origin due to the weathering of the lavas and breccias. There is no doubt of their quaternary age. This series is well exposed in the Tji Bodas near Kalidjati and again in the Sadawarna area. They have been subjected to earth-movement, and the southern junction with the grey shale series is everywhere a faulted one.

Recent Series.—These occupy the extreme northern portions of the area, near the coast. They consist of alluvial clays and coastal deposits. They are distinguished by the greyish or greenish colour of the soil.

COAL SEAMS FAULTED AGAINST BRECCIAS IN TJI KADOR, JAVA. D. E. I.

Age of the Strata.

In the notes on the Paleontology it has been made clear that while the general age of the strata has been determined, it is at present impossible to correlate the beds with the recognised subdivisions established in Europe. The Clay group is clearly of Miocene age and may even extend into the Pliocene period. This is especially so in Krawang, Batavia and Cheribon.

Messrs. Fennema and Verbeek have divided the Miocene group into three divisions, and have stated their relative age as below, No. 1 being the oldest :—

3. Calcareous group M_3.
2. Clay Shale group M_2.
1. Breccia group M_1.

The detailed mapping of the Tji Asem Lands on a large scale has proved in this area that the above is not the succession. Here the calcareous group is absent, and the Clay shale group shows an upward transition into the basal beds of the breccia group, undoubtedly proving the clay group to be older than the breccias.

The writer has therefore classified the rocks as follows :—

3. Volcanics { Recent. / Older.
2. Breccia group.
1. Clay shale group.

The grey shale series have been recognised as older than the breccia beds for the following reasons :—

1. The grey clay shales in their upper horizons show many aspects in common with the basal beds of the breccia group, and show a gradual transition from one to the other. In most localities the field relation of the two groups is a faulted one. In the Tji Keroeh and the Tji Baregbeg these two groups are in conformable sequence and the transition and relative age clearly proved.

2. The grey shales have an older appearance than similar clays in the base of the breccia formation, the shales are frequently highly folded, much more so than those in the breccia group, and this in spite of the fact that the latter are nearer the centre of the island, where Messrs. Fennema and Verbeek state the strata are more highly folded. In many places the clays of the clay group have developed the structure known as " Paper shales," which is indicative

of considerable earth-movement. This structure is not common to the clay beds of the breccia group.

3. In a few localities, *e.g.*, the upper Tji Djere and the Rocang Gadjah, the breccias appear to pass gradually and conformably upwards into the basal beds of the older volcanics.

The lithological characteristics of the eruptive rocks also support the view that the breccias are post-Miocene in age. Messrs. Fennema and Verbeek recognise that their basal Miocene eruptive rocks were similar to those of the recent volcanic, being andesitic and basaltic. This similarity is explained, if they are recognised as the early eruptives of the volcanic outbreak, which commenced at the close of the Tertiary times and has continued until to-day. This reasoning also explains the absence of any signs of vulcanicity in Oligocene times; the absence of which is remarkable if the early Miocene period were an age of vulcanicity of such an extent as supposed by Messrs. Fennema and Verbeek. They are of opinion that at least 2000 such outbreaks as that which occurred in 1883 at Krakatau would be necessary to furnish the mass of the eruptive rocks they classify as basal Miocene.

Further the lithological composition of the shale group suggests that they are derived from the erosion of an Eocene land area—the diabases and gabbros of Eocene age furnishing the clays, and the sandy clays and sands of the transition beds being derived from the quartz porphyry and the Eocene sandstones. If the clays are later than the breccias it is difficult to explain the origin of the quartz in the sands of the transition series.

The Volcanic group has been divided into an older and a recent subdivision. The former have been displaced by the great faults which were formed during and after the earth-movements which affected the breccia and clay groups. The older subdivision must, therefore, be dated with the Quaternary sediments, while the later division is of recent age.

Geological Structure.

The Miocene beds of the Tji Asem area have been subjected to considerable earth-movement. The grey shales have been extensively folded. In the Tji Loedoeg (rt. bk. trib. of the Tji Lamaja) the clay beds are vertical, being folded into an acute anticline with an almost due North and South strike. In other areas the clays and the breccias are folded into a number of domes and basins, which have the major axis generally in an East and West direction. It is clear that this movement commenced in the upper clay shale

times, and continued throughout the breccia period, the upper beds of which are less affected by the movements than the lower ones. The result of this movement was a general uplift of the area, which "uplift" is shown by the more sandy character of the upper beds of the shales, and the presence of carbonaceous shales and coals in the transition beds and the breccia group. The upper beds of the breccia group were deposited on a land surface.

At the close of the older stage of the volcanics group, the movement became so acute that fractures developed. A number of faults have been traced and mapped, and they are seen to fall into two groups—one with an approximate East and West trend, and the other transverse to this direction. Messrs. Fennema and Verveek recognised many faults in other parts of the island, but none in this neighbourhood. They also recognise two groups of faults similar to that above. There is every likelihood that the fault mapped by them in Cheribon, South of Madjalengka, is the eastward continuation of the southern fault in the Tji Asem area.

The North and South faults appear to be of earlier age than the East and West ones. The latter took place in Quaternary times as they have thrown the quaternary beds down to the North against the shale group. These fractures are not sharp, but faulted ground often occur over as much as half a mile width of country. Evidences of these faults are very common, and the irregularities produced form marked features of the topography. Almost every stream bed shows clearly the two East and West faults, extensive landslides occurring in the faulted grey shale outcrops. These are also very marked in the rubber plantations which occur on the lines of the faults, notably in the Paseh and the Tji Bakom gardens. The pipe-line from the reservoir to the power house at Goenoeng Toea crosses the southern fault, and caused much anxiety during the laying of this line. There is little doubt that several North and South faults are hidden under the recent volcanics.

Messrs. Fennema and Verbeek interpret the general structure of the island as that of an anticlinorum, which is highly folded in the centre, with gentler dips toward the North and South. They regard the South coast line as determined by a fault, to which they assign a probable Devonian age. It seems more likely that this fault is of the same age as the other faults parallel to it. The anticlinorum structure is not supported by the examination of the Tji Asem Lands. Here the breccias, which are nearer the centre of the island than the clay shales, are much less disturbed. The structure in this locality is that of a series of faulted domes and basins. What has happened in the South of this tract (*i.e.*, towards the centre of the island) cannot be determined as the whole is hidden under a mantle of newer volcanic intrusives and extrusives,

which most probably have been injected along the line of a fault. The main axis of uplift of the island can be traced by the outcrops of the Eocene and Cretaceous rocks, which are most probably the remnants of a much larger old land area.

Geological History.

The study of the Tji Asem Lands enables one to arrive at the sequence of events in this neighbourhood. The oldest rocks here exposed are the clay shale of Miocene (and probably Pliocene) age. This deposit shows relatively deep-water conditions, as the clay is very finely divided and free from sands. The area of deposition at that time must have been sufficiently far removed from the coast-line to be beyond the zone of sand deposition. In Preanger (Tji Mandiri and Radjamandala) are some limestones which are of lower Miocene age and indicate clear-water conditions there. At the close of the clay shale times, the area was subjected to earth-movement, which uplifted it and brought in shallow-water conditions as instanced by the sandstones and carbonaceous shales. These conditions continued well into breccia times, when, either by continued uplift or by excessive deposition (most probably the former), land conditions were brought about, the coast line being driven further to the North. In the clay shale times the land area most probably consisted of the Eocene beds. Simultaneously with this uplift volcanic eruptions took place on an extensive scale, as indicated by the enormous deposits of igneous breccias. These eruptions were of the explosive type, as instanced by the breccias. Messrs. Fennema and Verbeek express the view that these breccias and associated igneous rocks were the result of a fissure type of eruption, as they were unable to trace the craters, and they contend that the long ridges of igneous rocks in South Preanger can best be accounted for by such an hypothesis. It is difficult to understand the occurrence of such large masses of breccia from fissure eruptions. (None are found with the Deccan traps of India.) The absence of craters is easily understood, as any such would have been obliterated by the subsequent volcanic outbursts. Again it has been pointed out in the text that the breccias are more predominant and coarser in the South-east of the area, and that lavas are met with more in the West. This would further indicate that the centre of activity in this locality was to the South-east, probably in the neighbourhood of Boukit Tounggoul and Tangkoeban Prahoe. An interesting example of the lavas flowing into shallow water was noted in the Tji Selangwi, where a lava flow is seen ending abruptly against a carbonaceous shale. This lava also contained fossil wood.

The earth-movement which commenced at the close of the clay shale times, folded the clay shales and the lower members of the breccia group into a series of domes and basins. The uplifted areas were subject to contemporaneous erosion, thus accounting for the difficulty of differentiating between detrital and volcanic beds in the upper group. Two large domes have been recognised in this locality—one in the Tji Lamaja valley, and the other to the South-east beyond the Tji Poenagara valley. This movement continued into Quaternary times, when it became so acute that fractures developed, affecting the early quaternary and all older beds. A period of quiescence followed when denudation carved out a topography similar to that existent to-day. There was a central range with a parallel range of foot-hills to the North (remnants of the latter appear in the G. Njerengek, G. Tji Kadoe, G. Koedjang and G. Njomot). The final stage was the recrudescence of volcanic activity with outpourings of breccias and lavas. The source of these was undoubtedly the G. Tangkoeban Prahoe, and the eruptions took place entirely above the sea-level. The lavas from this volcano poured down the drainage channels. The whole of the head-waters of the Tji Lamatan was filled and the valley obliterated. This area is now drained by the Tji Nangka, which flows into the Tji Asem. The latter valley was filled with an immense basaltic lava flow as far downstream as Tjoeroegaggoeng and the Tji Lamaja as far down stream as Tji Reundeuj.

Petroleum.

Java has long been known as an oil producer. In 1900 the output was about 80,000 tons per annum and for the past twelve years has exceeded 200,000 tons per annum. The latest figures, those of 1923, are as follows:—

Rembang	242,135
Sourabaya	58,444
Semerang	1,993
Madura	12
Total	302,584 tons.

The principal oil pools are those of Tinawoen and Panolan in the Rembang area, which furnished 77,000 and 132,000 tons respectively in 1923. Formerly the Kutei and Lidah pools situated south and south-west of Sourabaya furnished the major portion of the output, but in 1923 these two pools together only yielded 8000 tons.

The wells vary from 500 to 800 feet in depth, and the yields are usually low, but are sustained for considerable periods. The whole of the production is from the clayey sandstones, which are either in the clay shale group or in the base of the calcareous group.

There does not appear to be a good reservoir rock in this area, and this doubtless explains the low yield of the wells.

Numerous indications of oil are found scattered throughout Java, and several localities have been tested with unfavourable results. The proved productive area lies in the country between Semerang and Sourabaya and extends across to Madura. There is no doubt that several areas have been ruined as potential oil-fields by the volcanic activity of relatively recent times.

The oil varies in specific gravity between 0·916 and 0·825. The average yield is 51 per cent. light oils, 42 per cent. lubricating oils, and 7 per cent. of paraffin wax. There are three refineries situated at Rembang, Semerang and Sourabaya, and also a candle factory.

Origin of Petroleum.

Petroleum occurrences are known in close proximity to volcanoes in this island, and these have often been quoted by the upholders of the theory of volcanic origin of petroleum. In 1896, Messrs. Fennema and Verbeek suggested that the oil was derived from the foraminifera, which are so plentiful in the limestone stage of the Miocene rocks of the Rembang area. There are no calcareous beds in the Tji Asem Lands, so that it is difficult to see how this view can hold good and account for the oil in this region. During the examination of the lands, all the oil indications were in the passage beds between the clay shales and the breccias. At this horizon there are numerous indications of the presence of vegetable matter, and signs of deposition close to a shore line. These transition beds include carbonaceous shales, brown coals and shales with plant remains, sandy shales with fossil wood. The conditions therefore at the close of the shale period were undoubtedly favourable for the entombment of vegetable matter. The beds were deposited in shallow water close to a coast on which there was heavy tropical vegetation. In the Tji Asem lands the entombment of vegetable matter was arrested by the outburst of volcanic activity, either by the killing of the vegetation or more probably by the raising of the land above sea-level. There is little doubt that the oil of this region is derived from the decomposition of vegetable matter entombed in the Miocene strata, and it is exceedingly probable that the same is true of those of the Eastern Java.

Hot Springs.

Messrs. Fennema and Verbeek record numerous occurrences of hot springs throughout Java, and have recognised three groups :—

1. Those associated with volcanoes.

2. Those associated with petroleum and gas, all of which are rich in salt, and some carry appreciable quantities of NaI and Na Br.
3. Those with no sign of petroleum and containing salt and a relatively large amount of Calcium Chloride.

The first group are always in proximity to volcanoes, either in the active or solfataric stage. These waters are characterised by the low percentage of solid matter, which averages about 4·5 parts per thousand.

The second group occur principally in the proved petroliferous belt between Semerang and Sourabaya, and except the one at Grobogan, where they issue from the quaternary beds, are from the Miocene strata. Three springs yielding iodide and bromide are found near Sourabaya at Kalangiar, Goenoekaratoe, and Kedoengwaroe. The following analyses are taken from Messrs. Fennema and Verbeek's work:—

	Kalangiar.	Goenoekaratoe.	Kedoengwaroe.
Na Cl	24·10	23·92	26·25
CO_3 and SO_4	1·79	1·94	—
Na I	0·11	0·12	0·171
Na Br	0·09	0·03	—
Solid matter per 1000 ..	26·69	26·01	29·171

A number of hot springs of this group have been worked for common salt, and in 1895 in the Miocene hills extending from the river south of Sourabaya westwards towards Semerang yielded 916,425 kg. of salt. Similar springs are found to the west in Cheribon and Krawang. The third group are characterised by their high percentage of calcium chloride and are found in three widely separated localities. The following analyses are given by Messrs. Fennema and Verbeek:—

	A.	B.	C.
NaCl	83·59	5·31	12·7
CaCl	24·70	6·09	5·5
Solid matter per 1,000..	118·29	11·86	19·5

A from Keboedanas, near Buitenzorg.
B „ Alian in Beguelen.
C „ N.E. of Poerworedoe, Beguelen and Banjoemas boundary.

In the Tji Asem area there are a number of hot springs. Many of these were undoubtedly associated with the volcano, Tangkoeban Prahoe. They invariably issue from under the basaltic lava flows, and several of them are associated with tufaceous deposits of calcium carbonate, which is undoubtedly derived from the decomposition of the felspars of the lavas.

The occurrence at Tji Baroeboes is unique and deserves special notice. Here are numerous hot springs issuing from the alluvial flat at the junction of two streams near Batoe Gede. From the rice lands here there are also intermittent emissions of carbon dioxide gas. A short distance away there are emissions of sulphuretted hydrogen gas, and from the Miocene strata exposed in the stream bed there are intermittent emissions of natural gas with a little oil. It was difficult to decide into which of the above categories these springs should be placed. The geology of the area is difficult, as the outcrops of the Miocene beds are few, only being found where the bed of the stream has cut sufficiently deep to cut through the overlying volcanics, which are partly of the older and partly of the recent subdivisions. A careful examination proved the presence of a north and south fault, which had occurred earlier than the recent volcanic period. Into this fault plane there was intruded a felspathic breccia, the felspars of which were decomposed into kaolin. The sulphuretted hydrogen emissions were in this breccia and in the line of this fault only. This rock was also found on the north side of the G. Njomot range, but here there were no gas emissions. The association of the carbon dioxide, and oil is undoubtedly fortuitous. The oil is derived from the sandy clays of the transitional beds between the clay shale group and the breccia beds; the carbon dioxide and sulphuretted hydrogen is from the volcanic source and with the hot waters have percolated along the line of the fault from the Tangkoeban Prahoe area and come to the surface in this the first valley to the north cut through the recent volcanics.

Sulphur and Gypsum.

The only sulphur known in Java is that found in the craters of some of the volcanoes. Small deposits of this mineral are found in the fumaroles in the craters of Tangkoeban Prahoe.

No beds of gypsum have been discovered in the island, but some clay shales in Cheribon contain small crystals of this mineral.

Conclusion.

In conclusion, the writer wishes to express his gratitude to the Chairman and Directors of the Anglo-Dutch Plantations of Java, Ltd., for allowing him to use information gained during work done on their behalf, and also for the loan of maps, etc.

He also wishes to acknowledge his indebtedness to the publication of Messrs. Fennema and Verbeek on the "Geology of Java"; liberal use of which has been made in the preparation of this paper.

DISCUSSION.

The Chairman said he was sure the members had listened with the greatest pleasure to the paper which had been read. Personally, he knew practically nothing about Java and therefore did not propose to make any remarks on the paper beyond asking the author one question, namely, whether the paper shales which the author mentioned were actually true paper shales similar to those which existed in Brazil.

Mr. E. H. Cunningham Craig, in opening the discussion, said that as a geologist he had listened with the very greatest pleasure to the paper and desired to thank the author for having read it before the Institution. One point differentiated it from most of the geological papers that had been read at the Institution, namely, that it was founded upon 6-inch maps. Geological notes were often put before the Institution, sometimes from previous publications and sometimes from the records of casual observations, but the paper that had been read was founded upon 6-inch mapping which had obviously been very carefully done and which stated the facts which had enabled the author to improve upon and modify many of the conclusions that the great geologists Fennema and Verbeek came to long ago. As long as work was founded upon 6-inch mapping it was always certain that, although the facts might not always be correctly understood, nevertheless facts were being presented. Personally he had spent a very pleasant time in Java. He had not been over the ground that the author had mapped, but he had been fairly near it, a little farther to the east, and Tangkoeban Prahoe was a well known landmark to him night and morning in going out to work and coming back again. The great difficulty in Java in the Tertiary formation was to work out the stratigraphy in detail. As the author had pointed out, fossils were not very numerous and only occurred at a few horizons. He had found that fossils were fairly common about the upper part of the middle Miocene. Very good faunas were to be found there sometimes, but when it came to the lower Miocene the fossils were very few and far between. He had been hoping that the author would have told the members more about the fossil evidence and how he distinguished the different groups. Personally, he found that in the lower Miocene, which he took it would correlate with the author's Breccia and clay group, fossils were very infrequent. He had seen a certain number of broken forms, bits of oyster shells and things of that kind, but nothing that could be actually identified and to which a specific name could be given. In the part of the country that he examined chiefly he found that the upper Miocene generally began with a coral limestone, which was flexured in some places along slightly

different lines from the flexures that affected the middle and lower Miocene. The great difficulty he had was in distinguishing between the lower and the middle Miocene, the difficulty being in finding some horizon where he could draw a line that he could prove over a considerable area. One of the reasons for that was that there was a very great natural variation in the rocks. He had had an assistant in Java, Mr. W. R. S. Henderson, for more than two years who had covered a tremendous amount of ground and who had worked out the courses of the Miocene deltas, showing where the sands were deposited and where they passed over gradually into the clays. He had been able to distinguish those deltas with considerable accuracy, and he had shown exceedingly well how the numerous seepages of oil, of which he had seen hundreds, were grouped round the deltas and occurred chiefly where there were really good sand beds alternating with good shales. He thought it was almost impossible to correlate the stratigraphy with European results, and also that it was unnecessary. It was much more to the point to correlate with India or Burmah. When he (Mr. Cunningham Craig) was working on the fossils of Burmah he found Martin's beautifully reproduced figures of the greatest use in helping him to identify forms in Burmah that had not been discovered in that country before. It was soon found that the published figures in Martin's book agreed in regard to the narrow thickness of the fossiliferous strata and that there was no very great variations in fauna. Java having helped Burmah in that way, he thought the time had now come when Burmah could help Java, because in the Pegu series in Burmah, a series of some 10,000 ft. in thickness, they were able to distinguish five or six pretty well defined zones. Of those he could only identify about one zone so far as his experience in Java went. He hoped the author would be able to give the members a little more information about the fossils to which he had referred. The paper was, he thought, a very great addition to their knowledge of Java, which was a most fascinating country. He was firmly convinced that so far as oil was concerned they had not seen anything like the best from Java yet; and that a great many places that had been overlooked, perhaps because they wanted a little more careful examination than had been given them by former geologists, would turn out to be excellent oilfields.

Mr. A. MacDougall asked the author if he could state the approximate distance from the volcanic area to the oil area in Java.

Mr. Ernest Parsons, in reply to the Chairman's question, said that unfortunately he did not know anything about the paper shales of Brazil as he had not visited Brazil and had not had an

opportunity of examining them. It could not be said, however, that the Java shales to which he had referred in the paper were true paper shales. It was only in limited areas, where the earth movement had been particularly acute; in the region of the faults and in the region of high compression in the cores of the anticlines, that an incipient cleavage had been developed suggestive of paper shales. With regard to Mr. Cunningham Craig's remarks, he confessed at once that he had not paid very great attention to the fossils of the area, simply because they were only found in one horizon which was perfectly clear at the top of the clay shale group and the base of the Breccia group. The principal fossil was a Turritella, of what species he could not say. There could be no doubt, however, that an examination of the fossils in that region would not help in regard to the matter of the relative age of the strata, because the fossils were restricted to one horizon only. He quite agreed with the remarks Mr. Cunningham Craig had made in regard to correlation. There could be no doubt that a correlation of the faunas from Burmah and Java would be extremely useful; but it must be remembered that, except for the upper Miocene in the more or less established oil region round Rembang, the fossiliferous horizons were extremely limited. Speaking from memory he believed that the Oligocene beds were at the most 100 metres thick in Nanggoellan, in an extremely restricted area with not more than two or three clear square miles of outcrop, and the only Oligocene beds in other parts varied from 10 to 50 metres in thickness. When one realised, therefore, the limited thickness of the strata from which fossils were found, the limitations of the paleontological establishment of the relative age of the Java series was readily recognised. The last question he was asked related to the distance from the volcano to the oil. There were three craters of any size and the nearest oil seepage was about 2½ miles distant. He did not think, however, the question of distance was of much vital importance. The real importance was that the seepage occurred at the first outcrop of the Miocene beds, which were the oil beds. The question of the relative position of the volcanic series, which was largely an extrusive one, and the oil beds was merely a matter of local occurrence. He was greatly indebted to the members for the patient way in which they had listened to his paper, and particularly to the speakers for the kind remarks they had made.

On the motion of the Chairman, a hearty vote of thanks was accorded to the author for his excellent paper, and the meeting terminated.

Oil Finding by Geophysical Methods.

By W. H. FORDHAM, M.A.

THIS paper contains a general description of the subject, indicating in what publications further information can be obtained; with, in addition, a number of formulæ used in Gravitational Surveys, which will help to give the student some idea of Potential, a conception intimately connected with all geophysical work.

The questions of interest are whether any geophysical means enable (1) the presence of oil to be directly proved, and (2) the tectonic configurations, which have caused, or accompany, accumulations of oil, to be located.

The methods to be considered are:—

(*a*) Magnetic;
(*b*) Electric;
(*c*) Gravitational.

(1) *Methods enabling the presence of oil to be directly proved.*—There is no geophysical method yet available for doing this, though it is just possible that electric or electro-magnetic means may be developed

(*b*) *Electric.*—The nearest approach to the required means is an instrument, advertised as a "Water and Oil-Finder," which purports to detect water and oil through the accompanying natural electric phenomena (6*a*).

Prof. Schlumberger has shown (8*a*) that natural electric currents are found above underground water in motion, as well as near minerals undergoing oxidation, but how oil deposits can cause similar reactions is difficult to explain.

The electric method of mineral research, using an artificial current, may, however, prove useful for locating oil under certain conditions.

It is theoretically possible and should prove feasible in practice to locate a considerable body of non-conducting mineral, such as oil, at a depth of several hundred yards, if there is no water horizon above the deposit. If further the deposit is sealed by saline water, the electric reactions will be more definite. (7 and 12*a*.)

(2) *Methods enabling the tectonic configurations, which have caused, or accompany, accumulations of oil, to be located.*

(*a*) *Magnetic method.*—This is not in itself of great value, and

All *a* references relate to the bibliography which is appended.

its interest lies in the apparent connection between magnetic and gravitational anomalies.

The observation of the latter is of great importance in Oil-Finding, and Dr. Mühlberg has lately suggested (3*a*) that, as magnetic anomalies accompany gravitational anomalies and may be observed with far greater facility, it may be advisable to make a preliminary magnetic survey of any district, confining the subsequent gravitational survey to areas showing magnetic anomalies.

That certain bodies, as salt deposits and heavy beds containing iron, cause both gravitational and magnetic anomalies is clear, though it is not obvious in other cases why the two should occur together. The matter is worth investigating, however, as a magnetic survey can be carried out in less than one-tenth of the time of a gravitational survey. Instruments similar to that described by G. W. Walker (4 *a.b*), but designed to read to 5×10^{-5} C.G.S. units, should prove suitable for this purpose.

(*b*) *Electric method.*—This has not been applied on a sufficiently large scale to warrant any conclusion as to its practical value, though one would expect, by using an artificial current, to be able to detect faults, intrusions, and probably "buried hills." The method consists of passing an electric current between two earthed electrode systems, and finding the equipotential lines. These are refracted above the plane where bodies of different conductivities meet, separating above good conductors and coming closer together above bad conductors. Any of the ordinary electric systems can be used for this purpose, the Schlumberger (7*a*), Swedish (10*a*) or Smalzi (12*a*), though possibly the last would prove the easiest to apply.

(*c*) *Gravitational method.*—Certain tectonic configurations, accompanying oil, *E. G.* Domes with salt cores,* Anticlines with heavy cores, Faults, Dykes, etc., give rise to anomalies of gravitation large enough to be measured by the Eötvös torsion balance.

This instrument was designed in 1888 by the late Baron Roland von Eötvös, the Budapest physicist, and was first used for the Geodetic Research, for which it was intended.

Eötvös, however, soon perceived that the balance could be of great service to the geologist for discovering the structure of underlying formations, in localities where these are masked by superficial deposits; and under his direction several surveys were carried out to investigate this question (15 and 16*a*).

A number of authorities, Prof. Böckh (18*a*), Dr. Pekar (20*a*), Profs. Koenigsberger (2 and 32*a*) and Laska (26*a*), S. Powers (21*a*)

* These can also be located by the Seismic Method. (37*a*.)

and others, have lately pointed out the importance of the balance in oil geology.

Description of the instrument.—The Eötvös torsion balance consists of a light horizontal beam with weights at the ends suspended on a torsion wire. It differs from the earlier instruments of Cavendish and Coulomb in that one of the weights is suspended on a wire some distance below the beam, this distinctive feature enabling the "gradients" of gravity to be measured.

A mirror is fixed to the centre of the beam to enable its position to be read. In the old type of instruments this was done by means of a scale and telescope on a hinged telescope arm; in the newer types the optical arrangements are enclosed within the outer case of the instrument, and the position of the mirror is shown on a ground glass screen, or registered on a sensitive plate, some distance above the beam.

The original instrument had a single beam, but the present ones have two, hung side by side with the suspended weights at opposite ends, the whole system, which can be rotated about the vertical axis, being protected by a treble walled metallic case.

Eötvös experimented with several modifications of the balance, and the type and dimensions, which he ultimately adopted, have been retained in many of the modern balances, though it is now usual to substitute photographic recording of the beam position and mechanical rotation of the beam system, for the visual reading and hand rotation of the older designs.

The instruments of standard size, the Suss, Schweydar-Bamberg and Oertling are just over 6 ft. in height and weigh between 1½ and 2 cwt., while the Hecker is about two-thirds of this size and proportionately lighter.

It is by no means clear, however, that it is an advantage to reduce the size of the instrument, for if the sensitivity of the standard size is satisfactory for ordinary work, the same results with smaller instruments can only be obtained by reading the deflection of the beam more accurately or by reducing the breaking strain factor of safety of the torsion wire; this factor of safety is in ordinary cases less than two. In use, too, all the instruments require a specially designed heavy tent or hut to protect them from external influences, so that the actual gain in portability of the outfit in reducing the weight of the balance by one-third is not very considerable.

The theory of the torsion balance (13, 14, 17 and 24*a*).—A freely suspended beam, of the type described, comes to rest in a definite position under the influence of two force systems, gravity and the twisting of the torsion wire. The equation to this position, provided

the force of gravity varies uniformly over the whole suspended system, is:—

$$n_a - n = \frac{2DK}{\tau}\left[\left(\frac{\partial^2 U}{\partial y^2} - \frac{\partial^2 U}{\partial x^2}\right)\frac{\sin 2a}{2} + \frac{\partial^2 U}{\partial y \partial x}\cos 2a\right] + \frac{2Dmhl}{\tau}\left[\frac{\partial^2 U}{\partial y \partial z}\cos a - \frac{\partial^2 U}{\partial x \partial z}\sin a\right] \quad (1)$$

where U is the potential function due to the force of gravity; the X axis being taken as pointing to the geographical North, the Y axis East, and the Z axis vertically downwards, and the azimuth angle a measured from the X axis in the clockwise direction.

n_a is the scale reading when the beam is set in azimuth a;

n the scale reading when the beam is under zero torque—*i.e.*, in an unvarying gravity field;

D† the distance, in scale units, between the scale and the mirror (1,200 to 1,500);

K† the moment of inertia of the suspended system (24,000 grm/cm.²)

τ† the co-efficient of the torsion wire (0·4)

m† the mass of the suspended weight (25 grm.);

h† the length of the wire on which it is suspended (65 cm.); and

l† the half-length of the beam (20 cm.)

The quantities D, m, h and l, can be actually measured.

K can be obtained by calculation or by hanging the suspended weight immediately below the beam, fixing the system thus formed on to a suitable wire and measuring its period of oscillation T_0. Weights m_1 are now fixed to the beam at such a distance from the centre as to give an added moment of inertia I, and the new period of oscillation T_1 is measured; K is then equal to

$$I\frac{T_0^2}{T_1^2 - T_0^2} \quad (2)$$

τ can be measured by placing a heavy spherical mass M first on one side of the suspended weight m at a distance ρ from it, and then on the opposite side at the same distance, and noting the deflection, $n_1 - n_2$, of the beam,

$$\tau \text{ being equal to } \frac{4D}{n_1 - n_2} \cdot \frac{GMm}{\rho^2} \cdot \frac{l}{\sqrt{1 + \frac{\lambda^2}{4\rho^2}}}. \quad (3)$$

† The usual values of these quantities are given in brackets.

where G is the gravity constant $= 66{\cdot}3\times10^{-9}$ C.G.S. units, and λ is the length of the suspended cylinder. The instrument constants

$$\frac{2DK}{\tau} \text{ and } \frac{2Dmhl}{\tau}$$

can thus be found, and by taking readings of n_s in five different positions of the beam the four magnitudes

$$\left(\frac{\partial^2 U}{\partial y^2} - \frac{\partial^2 U}{\partial x^2}\right), \quad \frac{\partial^2 U}{\partial x \partial y}, \quad \frac{\partial^2 U}{\partial y \partial z} \text{ and } \frac{\partial^2 U}{\partial x \partial z}$$

can be obtained.

From the magnitudes $\left(\frac{\partial^2 U}{\partial y^2} - \frac{\partial^2 U}{\partial x^2}\right)$ and $\frac{\partial^2 U}{\partial x \partial y}$, or U_Δ and U_{xy}, to adopt Schweydar's notation, the "curvature value," or deviation of the "niveau" surface of gravity from the spherical form, may be obtained. This is measured by the difference of the reciprocals of the principal radii of curvature $\frac{1}{\rho_1}$ and $\frac{1}{\rho_2}$, ρ_1 being the minimum and ρ_2 the maximum radius of curvature.

$$\frac{1}{\rho_1} - \frac{1}{\rho_2} = -\frac{U_\Delta}{g} \sec 2\lambda.$$

where λ gives the direction of ρ_2 the "minimum curvature" and is obtained from the equation

$$\tan 2\lambda = -\frac{2U_{xy}}{U_\Delta}.$$

The magnitudes

$$\frac{\partial^2 U}{\partial y \partial z} \text{ or } U_{yz} \text{ and } \frac{\partial^2 U}{\partial x \partial z} \text{ or } U_{xz}$$

represent the increase per unit distance of the vertical component of gravity in the horizontal plane in the easterly and northerly directions respectively

The maximum "gradient" of gravity is the resultant of these values, that is, it is equal to

$$+ \left\{(U_{yz})^2 + (U_{xz})^2\right\}^{\frac{1}{2}},$$

its direction being given by the equation

$$\tan \mu = \frac{U_{yz}}{U_{xz}}.$$

A balance survey consists of calculating these values at a number of points in the area under investigation; correcting these measured values for normal earth effects, superficial effects, and in some cases known subterranean effects, and plotting the final results

on a suitable scale on a plan of the area. These results, which are due to the unknown subterranean effects, are then compared with those found in areas of known geological structure or with the theoretical effects due to hypothetical structures, and inferences made as to the actual structure.

The balance in practice.—The equation to the balance as actually used is :—

$$N_\alpha = n_\alpha - n = \frac{P}{2} \cdot \sin 2\alpha \cdot U_\Delta + P \cos 2\alpha \cdot U_{xy} - Q \sin\alpha \cdot U_{xz} + Q \cos\alpha \cdot U_{yz} \qquad (4)$$

where $N\alpha$ is the deflection of the beam in scale units when set in azimuth α, and P, Q are the instrument constants.

In the equation to the double beam instrument N, n, P, and Q are usually taken to be the values for the "A," or No. 1 beam, the suspended weight of which is set to point north in the 0° azimuth of the instrument, which N^1, n^1, P^1 and Q^1 refer to the "B" or No. 2 beam, which points south in the 0° azimuth. If observations are made in the three azimuth 0°, 120° and 240°, the solution of the six equations gives the following results :—

R being a new constant equal to PQ^1+QP^1 :—

$$\begin{aligned}
U_\Delta &= \frac{2Q}{R\sqrt{3}} \left\{ \frac{Q^1}{Q} (N_{240}-N_{120}) + (N^1_{240}-N^1_{120}) \right\} \\
U_{xy} &= \frac{Q}{R} \left\{ \frac{Q^1}{Q} \cdot N_0 + N^1_0 \right\} \\
U_{xz} &= \frac{P}{R\sqrt{3}} \left\{ \frac{P^1}{P} (N_{240}-N_{120}) - (N^1_{240}-N^1_{120}) \right\} \qquad (5) \\
U_{yz} &= \frac{P}{R} \left\{ \frac{P^1}{P} \cdot N_0 - N^1_0 \right\}
\end{aligned}$$

$$N_0+N_{120}+N_{240}=0 \qquad N^1_0+N^1_{120}+N^1_{240}=0$$

$$i.e.,\ n = \frac{n_0+n_{120}+n_{240}}{3} \text{ and } n^1 = \frac{n^1_0+n^1_{120}+n^1_{240}}{3}.$$

In actual use, owing to the shift of the zero positions of the beams, it is necessary to repeat one or more of the observations, and either average the results or eliminate unsatisfactory readings.

With the instruments used by Eötvös two hours were required between observations, to allow the beam to come to rest after being disturbed; now, with improved air damping, one hour usually suffices. Even so, at any station where the minimum of four observations are made, four hours are required after the instrument has been adjusted.

Eötvös found that observations made by night were more satisfactory than those made by day, owing to the less rapid temperature changes, and though attempts are continually being made to protect the instruments sufficiently from external effects to render day observations accurate, the end can, as yet, scarcely be said to have been attained. In any balance survey the question really is, what accuracy is needed in the final results to enable the required deductions as to structure to be made with reasonable certainty?

Eötvös pointed out that with any system of reading, whereby a tenth of a minute could be measured, the period of oscillation of the suspended system must exceed ten minutes, to enable a sensitivity of 1×10^{-9} C.G.S. units to be obtained. He considered that with his instruments, which possessed a period of swing of nearly twelve minutes, it was possible to obtain results to within considerably less than 1 Eötvös unit.*

It is not contended that so great an accuracy as Eötvös obtained is necessary in surveys made to locate oilfields, though probably it is possible, and perhaps necessary, to work to within about 2 Eötvös units.

If it is once shown that in any district the anomalies of gravity accompanying oil are sufficiently great to be detected when working with an accuracy of 3 or 4 units, day readings may be preferable to night readings, with two or three stations occupied by each balance in twenty-four hours, and even a small type of balance employed.

Before considering station corrections it may be worth mentioning that in the event of one of the torsion wires, in a double beam instrument, being broken, it is possible by taking readings every 90° to obtain the gradient values with one beam only, the solutions to the four equations being:—

$$\begin{aligned}
U_{xy} &= \frac{1}{2P}(N_0 + N_{180}) = -\frac{1}{2P}(N_{90} + N_{270}) \\
U_{xz} &= \frac{1}{2Q}(N_{270} - N_{90}) \\
U_{yz} &= \frac{1}{2Q}(N_0 - N_{180}) \qquad (6) \\
N_0 + N_{90} + N_{180} + N_{270} &= 0 \\
i.e.,\ n &= \frac{n_0 + n_{90} + n_{180} + n_{270}}{4}
\end{aligned}$$

U_A not being determined.

*Prof. Schweydar has proposed that 1×10^{-9} C.G.S. should be called 1 Eötvös unit, and written 1 E. (23a).

Station Values.

The following is a convenient nomenclature, though it differs slightly from that adopted by Eötvös :—

(*a*) *Observed values* for the values actually calculated from the instrument readings by equations (5).

(*b*) *Normal earth effects*, for the values due to the geoid form of the earth, and which may be calculated from one of Helmert's formulæ for g.

(*c*) *Terrain effects* for the values due to superficial irregularities in the immediate neighbourhood of the station, and which are calculated from data obtained by levelling.

(*d*) *Topographical effects* (or cartographic effects) for the values due to features further from the station than those treated as terrain effects, and which are usually calculated from maps.

(*e*) *Subterranean effects*, for the values due to hidden geological structures.

The subterranean effects are obtained by subtracting the topographical, terrain and normal earth effects from the observed values.

(*b*) *Normal earth effects.*—If the form of the geoid is taken as the normal Bessel Ellipsoid, and Hedlmert's 1896 formulæ for g is selected :—

i.e., $g = 978\ (1 \times 0{\cdot}0053 \sin^2\phi)$ C.G.S. units, where ϕ is the latitude.

$$U_{yz} = 0 \quad , \quad U_{xy} = 0$$

$$U_{xz} = \frac{dg}{dx} = \frac{dg}{d\phi} \cdot \frac{d\phi}{dx} = \frac{1}{R\phi}\ (978 \times 0{\cdot}0053 \sin 2\phi)$$

where $R\phi$ is the radius of curvature of the meridian section at ϕ.

R varies from about 637,740,000 cm. at the equator to 635,608,000 cm. at the poles, and for the purposes of this calculation the mean value 636,700,000 cm. may be taken. This gives :—

$$U_{xz} = 8{\cdot}15 \sin 2\phi \times 10^{-9} \qquad (7)$$

By a somewhat similar process it can be shown that :—

$$U_{\Delta} = 5{\cdot}15\ (1 + \cos 2\phi) \times 10^{-9}.$$

These equations give the values of U_{xz}, 0 at the equator and poles, $6{\cdot}24 \times 10^{-9}$ at lats. 25° and 65°, $8{\cdot}15 \times 10^{-9}$ at 45°, and of U_{Δ}, $10{\cdot}3 \times 10^{-9}$ at the equator, $8{\cdot}46 \times 10^{-9}$ at lat. 25°, $5{\cdot}15 \times 10^{-9}$ at 45°, $1{\cdot}21 \times 10^{-9}$ at 65°, and 0 at the poles.

(*c*) *Terrain effects.*—Levels are taken in eight directions N.($_0$), N.E.($_1$), E.($_2$), etc., from the balance station, the heights of the surface above the foot of the balance $\zeta o_{,1}$, $\zeta o_{,2}$, etc., being measured at fixed distances ρ_1, ρ_2, etc.

The distances selected by Eötvös were 1·5, 5, 20, 50 and 100 metres, which were, no doubt, suitable when working in the

Hungarian plain, but do not take into sufficient account the irregularities of the surface in the immediate neighbourhood of the balance station when in more broken country.

For this reason Schweydar prefers distances 1·5, 3, 5, 10, 20, 30, 40, 50, 70 and 100 metres for levelling purposes, calculating from maps the height of the surface at greater distances, 150, 250, 400 metres, etc.

In practice, however, it is not advisable to carry terrain corrections on this system much beyond 30 or 40 metres from the station, some form of topographical corrections with levels measured on a greater number of radii being more suitable for greater distances.

Schweydar gives the following formulæ (23*a*) for the Bamberg balance, for which he takes the height of the centre of gravity of the weights as 90 cm. above the level of the station.

$$\left.\begin{aligned}
U_{xx} &= \frac{\sigma}{2} E \left\{ 2{\cdot}36c_1 + 0{\cdot}643c_2 + 0{\cdot}239c_3 + 0{\cdot}082c_4 + 0{\cdot}0186c_5 + \dots \right\} \\
U_{yy} &= \frac{\sigma}{2} E \left\{ 2{\cdot}36b_1 + 0{\cdot}643b_2 + 0{\cdot}239b_3 + 0{\cdot}082b_4 + 0{\cdot}0186b_5 + \dots \right\} \\
-U_{\Delta} &= \frac{\sigma}{2} E \left\{ 3{\cdot}302e_1 + 1{\cdot}962e_2 + 1{\cdot}343e_3 + 0{\cdot}844e_4 + 0{\cdot}357e_5 + \dots \right\} \\
2U_{xy} &= \frac{\sigma}{2} E \left\{ 3{\cdot}302d_1 + 1{\cdot}962d_2 + 1{\cdot}343d_3 + 0{\cdot}844d_4 + 0{\cdot}357d_5 + \dots \right\}
\end{aligned}\right\} \quad (8)$$

where $E = 1$ Eötvös $= 1 \times 10^{-9}$ C.G.S. unit; σ The specific gravity of the surface formations—*i.e.*, about 1·8; and c_1 c_2, etc., are obtained from the levelling data at the distances $\rho_1 = 1{\cdot}5$ M., $\rho_2 = 3$ M., etc., by means of the formulæ :—

$$\left.\begin{aligned}
4c_n &= \zeta_0 - \zeta_4 + 0{\cdot}707\,(\zeta_1 - \zeta_3 - \zeta_5 + \zeta_7) \\
4b_n &= \zeta_2 - \zeta_6 + 0{\cdot}707\,(\zeta_1 + \zeta_3 - \zeta_5 - \zeta_7) \\
4e_n &= \zeta_0 - \zeta_2 + \zeta_4 - \zeta_6 \\
4d_n &= \zeta_1 - \zeta_3 + \zeta_5 - \zeta_7
\end{aligned}\right\} \quad (9)$$

the ζ's being measured in centimetres, + if above, − if below the plane through the foot of the balance, and here numbered from 0 to 7 instead of from 1 to 8 as is done by Schweydar.

Similar formulæ, for surveys made in feet, are :—

$$\left.\begin{aligned}
U_{xx} &= 10^{-9} \times \sigma \left\{ 36{\cdot}8c_1 + 6{\cdot}72c_2 + 3{\cdot}91c_3 + 1{\cdot}47c_4 + 0{\cdot}940c_5 + 0{\cdot}407c_6 + 0{\cdot}099c_7 \right\} \\
U_{yy} &= 10^{-9} \times \sigma \left\{ 36{\cdot}8b_1 + 6{\cdot}72b_2 + 3{\cdot}91b_3 + 1{\cdot}47b_4 + 0{\cdot}940b_5 + 0{\cdot}407b_6 + 0{\cdot}099b_7 \right\} \\
-U_{\Delta} &= 10^{-9} \times \sigma \left\{ 45{\cdot}2e_1 + 34{\cdot}6e_2 + 9{\cdot}37e_3 + 10{\cdot}17e_4 + 9{\cdot}14e_5 + 7{\cdot}23e_6 + 8{\cdot}50e_7 \right\} \\
2U_{xy} &= 10^{-9} \times \sigma \left\{ 45{\cdot}2d_1 + 34{\cdot}6d_2 + 9{\cdot}37d_3 + 10{\cdot}17d_4 + 9{\cdot}14d_5 + 7{\cdot}23d_6 + 8{\cdot}50d_7 \right\}
\end{aligned}\right.$$

in C.G.S. units, where h is taken as 3 feet, and the respective values of ρ_1, ρ_2, etc., are 5, 10, 15, 20, 30, 50 and 100 feet.

The way in which these results have been obtained is indicated later (page 459).

It will be noticed from the formulæ that the corrections for "gradients" and "curvature values" depend on different superficial features, and that at a balance station on an even slope the "gradient" corrections are a maximum and the "curvature" corrections nil, while on uneven ground the former may be very small and the latter large.

The second point to notice is that the numerical co-efficients decrease far more rapidly for the "gradients" than for the "curvature values."

It is for these reasons that in present-day practice it is usual to concentrate on the "gradients," and to a very great extent neglect the "curvature values."

For it is evident from the size of these numerical co-efficients that terrain corrections are necessary, except in a perfectly flat country; and, owing to the uncertainty of these corrections, they should be reduced to a minimum; and this can be done, especially in the case of the "gradients," by a careful selection of balance stations. Superficial features, too, somewhat removed from the station, have less effect on "gradients" than on "curvature values," and so may more often be neglected.

Special corrections must be made for such features as cuttings and embankments. If near the balance station they may often be treated as infinitely long, formulæ (15) being applied.

(*d*) *Topographical effects.*—The gravity potential at the origin due to a mass m grams at the point (a, b, c) is:—

$U_0 = \frac{mG}{r}$ where G is the gravity constant and $r^2 = a^2 + b^2 + c^2$

$\therefore$ the gradient at the origin:—

$$U_{xz} = mG \cdot \frac{3ac}{r^5}.$$

In the case of a mass of finite dimensions this expression has to be integrated through the mass, so that, if the district round the balance B is divided up into segments by a number of radial lines and circles, the effect, due to the fact that the surface of the ground varies from the level plane passing through the foot of the balance, of one such segment (shown in Fig. 1) is, using polar co-ordinates:—

$$U_{xz} = 3G\sigma \int_{\theta_m}^{\theta_{m+1}} \int_{\rho_n}^{\rho_{n+1}} \int_{0}^{\zeta} (h-z) \frac{\rho^2 \cos\theta}{\{\rho^2 + (h-z)^2\}^{5/2}} \, d\theta d\rho dz \qquad (10)$$

where ζ is the height of the segment and h the effective height of the centre of the balance above the plane passing through the foot of the balance.

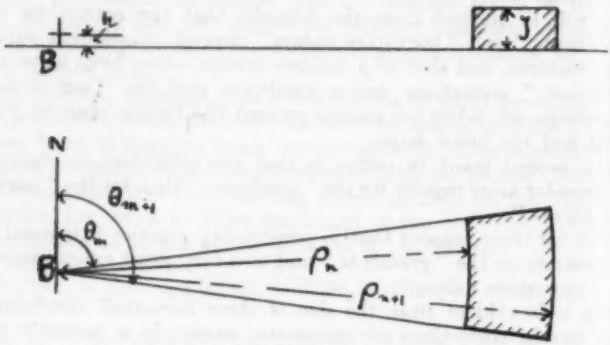


FIG. 1.

Topographical features are usually such that $(h-z)$ can be neglected with respect to ρ, in which case :—

$$U_{zz}=3\,G\,\sigma\int_{\theta_m}^{\theta_{m+1}}\int_{\rho_n}^{\rho_{n+1}}\int_{o}^{\zeta}\frac{\cdot(h-z)cos\theta}{\rho^3}\,d\theta d\rho dz$$

i.e., by carrying out the integration :—

$$\left.\begin{aligned}
U_{zz} &= +\frac{3}{2}\,G\,\sigma\,\zeta\left(\frac{\zeta}{2}-h\right)\left(\frac{1}{\rho^2_n}-\frac{1}{\rho^2_{n+1}}\right)\left(sin\theta_m-sin\theta_{m+1}\right)\\
&\text{Similarly :—}\\
U_{yz} &= +\frac{3}{2}\,G\,\sigma\,\zeta\left(\frac{\zeta}{2}-h\right)\left(\frac{1}{\rho^2_n}-\frac{1}{\rho^2_{n+1}}\right)\left(cos\theta_{m+1}-cos\theta_m\right)\\
U_{\Delta} &= -\frac{3}{2}\,G\,\sigma\,\zeta\left(\frac{1}{\rho_n}-\frac{1}{\rho_{n+1}}\right)\left(sin2\theta_m-sin2\theta_{m+1}\right)\\
2U_{xy} &= +\frac{3}{2}\,G\,\sigma\,\zeta\left(\frac{1}{\rho_n}-\frac{1}{\rho_{n+1}}\right)\left(cos2\theta_{m+1}-cos2\theta_m\right)
\end{aligned}\right\}\quad(11)$$

To apply these formulæ the district round the balance station may be divided into a number of radial segments, the sine and cosine factors being tabulated.

Eötvös used thirty-six equal segments and measured the distances to the contour lines in each segment, working out his corrections by horizontal sections.

If good maps are available this is probably a convenient method; if not, it is wiser to proceed as for terrain corrections, and measure

the height of the surface of the ground at fixed distances along a number of radii.

Thus if the terrain corrections are carried to 100 ft. from the balance, topographical corrections may be made by levelling on twenty-four radii at azimuths 0°, 15°, 30°, etc., taking levels at 100, 125, 150, 200, 250, 300 ft., etc.

Superficial features more distant than 300 ft. from the balance station can, as a rule, be neglected unless of considerable size. In this case they must be specially surveyed and their effects calculated, either by the preceding formulæ, or by one of the subterranean effect formulæ to be mentioned later.

The Calculation of Terrain Effect Formulæ.

Owing to the fact that in considering terrain effects it is not permissible to neglect $h-z$ with respect to ρ in equations (10) p. 457, the calculation of these formulæ is very tedious. (23 and 36a.)

The simplest method consists in taking the value of the integral

$$\int_0^{\zeta} \frac{(h-z)}{\{\rho^2+(h-z)^2\}^{3/2}}\,dz$$

as approximately equal to

$$\frac{h\zeta - \frac{\zeta^2}{2}}{(\rho^2+h^2)^{3/2}}$$

in which case the total effect of the zone bounded by the circles ρ_{n+1} and ρ_n is :—

$$U_{xzy} = 3\,G\sigma \int_0^{2\pi}\int_{\rho_n}^{\rho_{n+1}} \frac{\left(h\zeta - \frac{\zeta^2}{2}\right)\rho^2 \cos\theta\, d\theta\, d\rho}{(\rho^2+h^2)^{5/2}} \qquad (12)$$

The ζ's now have to be expressed in terms of θ and ρ. Eötvös did this by putting :—

$$\zeta = c + a\theta + b\rho\theta + d\rho$$

while Schweydar prefers to develope ζ as a Fourier series in θ and ρ.

Both methods enable the values of the integrals in equation (12) to be ultimately expressed in terms of the levelling data and h, especially if, as is usually done, the terms containing ζ^2 are neglected.

The last point to consider is h, the effective height of the centre of the balance (origin of co-ordinates) above the station level.

Eötvös took this as 1 metre,* which is the approximate height

* The formulæ calculated by Eötvös can be found in his 1906 report (pp. 358–360). (14 and 36a)

of the beam above the foot of the balance. Schweydar, however, considers that the centre of gravity of the weights should be chosen, that is about 70 cm.

As has been mentioned, Schweydar used the value 90 cm. in calculating his formulæ (p. 456) for, at that time, the Bamberg balance was placed on a platform 20 cm. high.

(*e*) *Subterranean effects.*—To interpret the subterranean effects obtained by subtracting the normal earth effects, terrain and topographical effects from the observed values, they are plotted on a suitable scale, 10E or 20E to 1 in., on a plan of the survey, an arrow being drawn from each balance station in the direction of the "resultant gradient" and a line through each station in the direction of the "minimum curvature," if curvature values are also being observed. At some convenient point in the survey the value of gravity is measured or assumed, and from the gradients the values of gravity at the balance station are calculated. It is dangerous to lay down any hard and fast rules for eliminating apparent errors while making these calculations, for the areas of interest in a survey are precisely those in which the variations of gravity are so local as to cause considerable closing errors, whatever system is adopted; and it is safer to calculate the values of gravity at the stations between which the variation is uniform, and then assume gradients at supplementary points of such magnitude and direction as will enable a reasonable series of isogams to be drawn. Isogams are lines of equal intensity of gravity, and may be plotted from the values of gravity at the balance stations; they may be looked on, roughly, as contour lines of bodies causing anomalies of gravity.

In Continental practice it is usual to put in isogams at 0·001 C.G.S. unit apart, a difference caused by a gradient value of 10E through one kilometre. On maps drawn to a scale of miles it is, however, more convenient to adopt the difference caused by 10E through half-a-mile on 0·000805 C.G.S. unit.

Formulæ for Calculating Subterranean Effects.

1. Heavy formation with a uniform sloping plane as its upper surface.

Eötvös showed out that the formula (14*a*)

$$\Delta g = 2\,\pi\,G\,(\sigma^1 - \sigma)h \qquad (13)$$

gives the relation between the decrease in gravity and the sinking of the heavier formation, $(\sigma^1\text{-}\sigma)$ being the difference in specific gravity of the underlying and overlying beds, and that the isogams are parallel straight lines at a uniform distance apart. This formula

is only true if the plane is infinite, and so should be applied cautiously in practice.

The following formulæ are obtained from the principles noticed on page 457, anexpression for the effect at the origin for a particle within the body being found and then integrated through the mass.

2. Infinite horizontal plate, bounded by a vertical plane parallel to the y axis. This is shown in section in Fig. 2, the vertical plane 3, 4 being imagined at infinity.

Eötvös pointed out that in this case (14*a*) :—

$$U_{xz} = 2\,G\,(\sigma^1 - \sigma)\,log_e \frac{\rho_2}{\rho_1} \qquad (14)$$

$U_{xx} = 2\,G\,(\sigma^1 - \sigma)(\theta_2 - \theta_1)$ where θ_2 and θ_1 are measured in radians. U_{xy}, U_{yz} and U_{yy} being equal to O, and consequently $U_\Delta = -U_{xx}$.

3. Infinite horizontal bar, bounded by vertical planes parallel to the y axis as shown in section in Fig. 2 :—

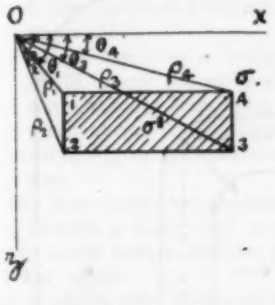


FIG. 2.

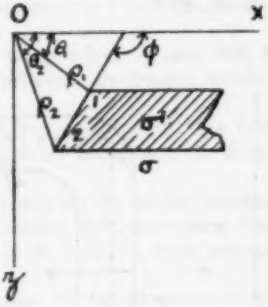


FIG. 3.

$$U_{xz} = 2\,G\,(\sigma^1 - \sigma)\,log_e \frac{\rho_2 \cdot \rho_4}{\rho_1 \cdot \rho_3}$$

$$U_{xx} = 2\,G\,(\sigma^1 - \sigma)\,(\theta_3 + \theta_4 - \theta_1 - \theta_2) \qquad (15)$$

These are obvious extensions of the previous formulæ.

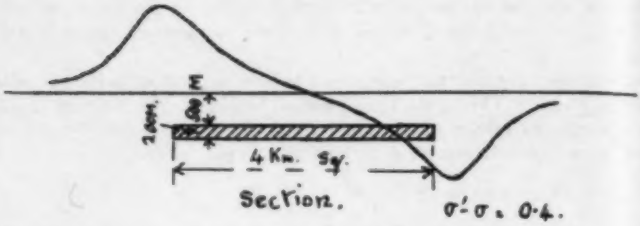
4. Rectangular block with sides parallel to the co-ordinate planes, the corner points being $(x_1\ y_1\ z_1)$ $(x_1\ y_1\ z_2)$, etc., Messrs. Shaw and Lancaster-Jones have pointed out (25*a*) that in this case :—

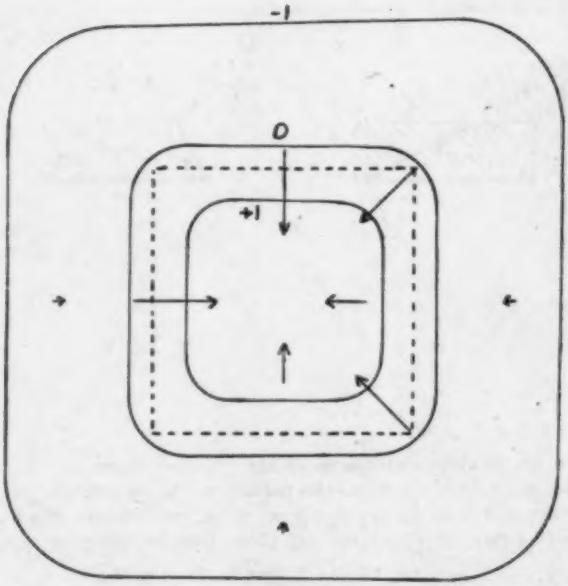
$$U_{xz} = G\,(\sigma^1 - \sigma) log_e \frac{(y_2+r_{222})(y_1+r_{211})(y_1+r_{112})(y_2+r_{121})}{(y_1+r_{111})(y_2+r_{122})(y_2+r_{221})(y_1+r_{212})} \qquad (16)$$

$$U_{yz} = G\,(\sigma^1 - \sigma) log_e \frac{(x_2+r_{222})(x_1+r_{121})(x_1+r_{112})(x_2+r_{211})}{(x_1+r_{111})(x_2+r_{212})(x_2+r_{221})(x_1+r_{122})}$$

where $r_{111} = \sqrt{x_1^2+y_1^2+z_1^2}$, etc.

5. Infinite horizontal plate, bounded by an inclined plane, parallel to the y axis, as shown in Fig. 3.





Plan.

Scale: 1 cm.=1 km.
Gradients: 1 cm.=10E.
Isogams: 0·001 C.G.S. Apart.

FIG. 4.

Mr. Lancaster-Jones has lately succeeded in obtaining the formulæ for this case* :—

$$U_{xz} = G(\sigma^1 - \sigma)\left\{2\sin^2\phi.\log_e\frac{\rho_2}{\rho_1} - (\theta_2 - \theta_1)\sin 2\phi\right\} \qquad (17)$$

$$U_{xx} = G(\sigma^1 - \sigma)\left\{\sin 2\phi.\log_e\frac{\rho_2}{\rho_1} + 2(\theta_2 - \theta_1)\sin^2\phi\right\}$$

These are general cases of formulæ (2), equations (14).

By using these formulæ, supplemented in certain cases by graphical methods, it is possible to obtain the theoretical effects due to various simple types of bodies.

Theoretical Subterranean Effects.

1. *Brachyanticline with heavy core.*—This case is designed to illustrate the Egbell and Sasvar Domes, described in Prof. Böckh's classic paper (18*a*).

The core is taken as a rectangular body 4 km. square, 200 M. thick, 500 M. below the surface, the difference in density between it and the overlying beds being 0·4.

The gradient profile, gradients and isogams due to this body are shown in Fig. 4, the maximum of gravity being over the centre of the core.

In Fig. 5 are shown the gradients and isogams due to the resultant effects of such a body, and a gravitational field increasing from north to south with a uniform gradient of 7 E, *i.e.*, with isogams 10÷7 km. apart.

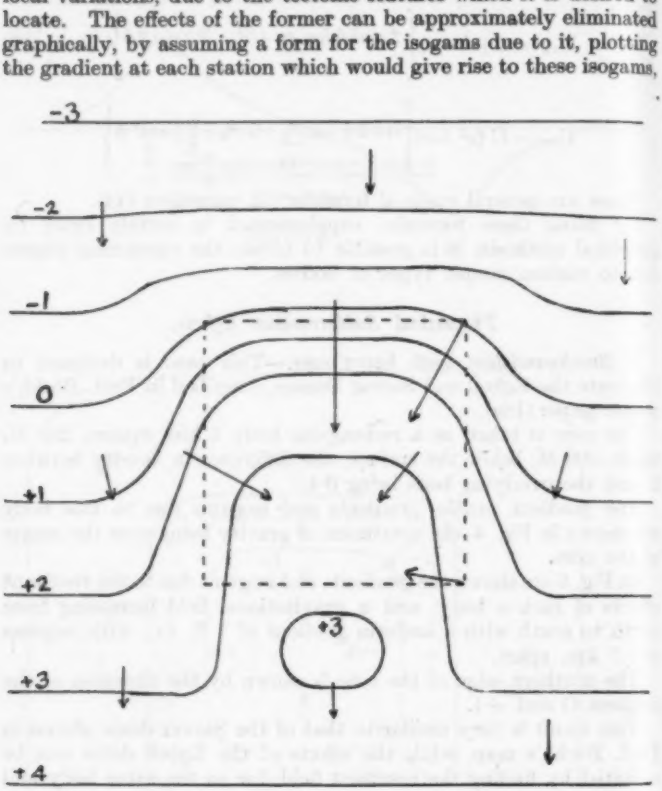
The northern edge of the core is shown by the closeness of the isogams 0 and +1.

This result is very similar to that of the Sasvar dome shown in Prof. Böckh's map, while the effects of the Egbell dome can be imitated by finding the resultant field due to the same body and a field with a fan-like arrangement of isogams, opening out towards the north.

This point is important in considering practical results, for one must not look upon these results as complete in themselves, but rather as the resultant of two gravity fields. The first a field varying more or less uniformly, due to extensive deep-seated subterranean bodies for which there is no means of making corrections directly, distant superficial features for which the effects are taken as uniform over the area of the survey, errors in correc-

* Privately communicated, not previously published.

tions for normal earth effects, etc., the second a field with rapid local variations, due to the tectonic features which it is desired to locate. The effects of the former can be approximately eliminated graphically, by assuming a form for the isogams due to it, plotting the gradient at each station which would give rise to these isogams,



Scale: 1 cm.=1 km.
Isogams, 0·001 C.G.S. Apart.

FIG. 5.

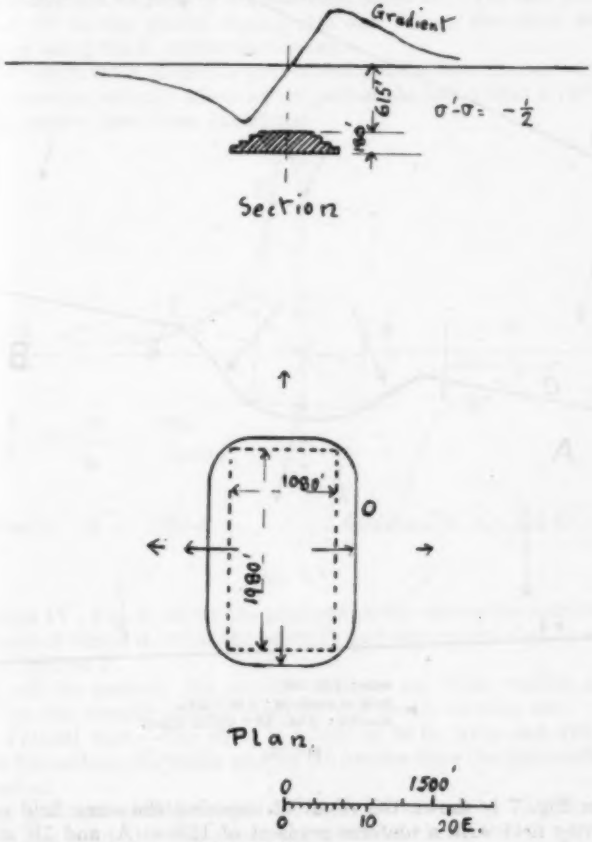
reversing the sign of the gradient and finding the resultant of it and the original subterranean value. These resultants are the gradients due to the tectonic features sought for, and the isogams due to them will indicate clearly the nature and position of these features.

This will be made clearer by comparing figures 4 with 5, and 6 with 7.

This is a much more general and satisfactory way of dealing with results than the ingenious method of "Kotiert Projection," due to Prof. Laska (27*a*).

2. *Dome with salt core.*—The core is taken as a bed 1,980 ft. long, 1,080 ft. broad, and 180 ft. thick, 615 ft. below the surface, of density 0·5 less than the overlying formation.

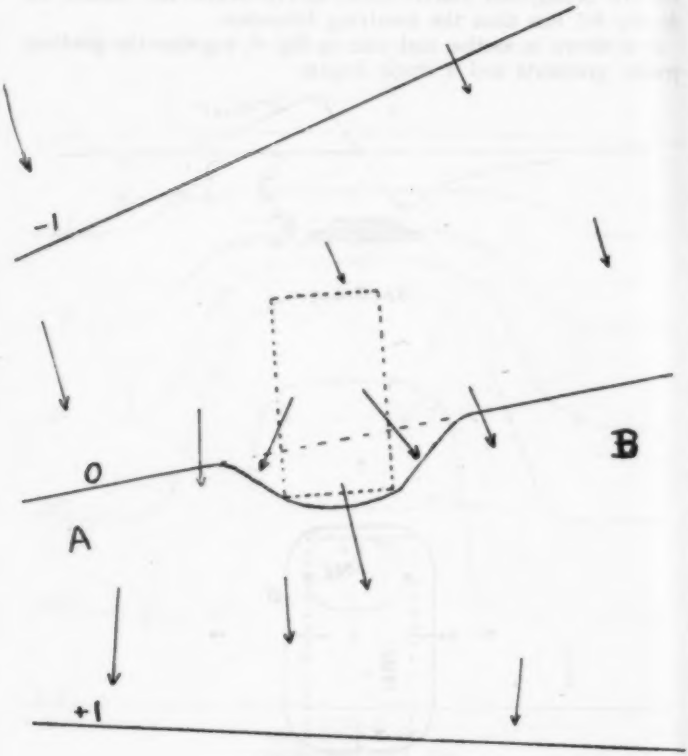
It is shown in section and plan in Fig. 6, together the gradient profile, gradients and a single isogam.



Scale: 1/20.000
Scale of gradients: 1 in. = 20E.

FIG. 6.

The gravity disturbance is less than $8{\cdot}05 \times 10^{-4}$ C.G.S. units, so that only one isogam is to be found in the field, and this will have an oval form, and may be drawn through any selected point. There is a minimum of gravity above the centre of the core.



Scale: 1/20,000.
Scale of gradients: 1 in. = 20E.
Isogams: $8{\cdot}05 \times 10^{-4}$ C.G.S. Apart.

FIG. 7.

In Fig. 7 is shown the result of imposing the same field on a gravity field with a uniform gradient of 12E at A, and 7E at B, the presence of the salt core being indicated by the deflection of isogam O.

3. *Sandstone lens in lighter formation.*—The lens is taken as 6,000 ft. long, 2,100 ft. broad, and 99 ft. thick, 900 ft. below the surface, of density 0·5 more than the surrounding formation.

Graphs 3 and A, Fig. 8, show the gradient and "curvature" profiles across the lens, the centre of which is below the point O.

The noticeable things about the "curvature" values are that the maximum occurs above the lens, and that they have a measureable magnitude over a larger area than the gradients.

4. *Heavy bed in form of asymmetrical anticline.*—The bed has a dip of 15° on the gently sloping side and 75° on the other side, its apex being 750 ft. below the surface.

It is 150 ft. thick of specific gravity 0·5 greater than the surrounding formation, and the effects of the part of the bed within 1,740 ft. of the surface have been calculated.

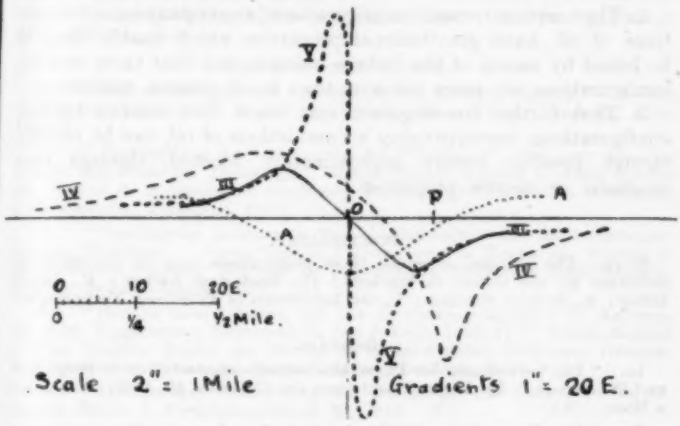


FIG. 8.

Graph IV., Fig. 8, shows the gradient profile across the anticline, the apex of which is below the point P, and the steeply sloping side to the right of P.

As will be noticed, the gravity changes are more sudden and local on the steeply sloping than on the gently sloping side.

5. *Vertical dyke.*—The dyke is taken as 90 ft. wide and 120 ft. below the surface, of specific gravity 0·5 greater than the surrounding formation.

The gradient profile across the dyke is shown by Graph V., Fig. 8, the point O being above the centre of the dyke.

The interesting points about these results are the distinctive forms of the profiles, and the comparatively small area over which

measurable gradient values are found; the latter is the factor which, to a great extent, decides the distance between balance stations.

In ordinary cases probably something less than half-a-mile is the largest distance permissible.

Conclusion.

The general conclusions reached from a study of Geophysical Literature are:—

1. That oil deposits do not appear to possess sufficiently definite physical properties, either magnetic, electric or gravitational, as to enable them to be directly discovered, except under rather uncommon circumstances.

2. That certain tectonic configurations, accompanying accumulations of oil, have gravitational properties which enable them to be found by means of the Eötvös balance, and that these tectonic configurations are more common than is, at present, realised.

3. That further investigation may show that various tectonic configurations, accompanying accumulations of oil, can be rapidly, though possibly merely approximately, located, through their magnetic or electric properties.

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Note.—The libraries at which these publications may be consulted are indicated by the letters in brackets: G., Geological Survey; P., Patent Office; S., Science Museum; I., the Institution of Petroleum Technologists.

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A Method for the Estimation of Water in Hydrocarbon Oils, Shales and Lignites.

By Charles Edmund Wood and Albert Edward Toney Neale.

There are three general methods in use for the estimation of water in oils, but certain of them present difficulty in analysis and are in some cases unsatisfactory. The first of these methods, that of centrifuging, is accurate according to L. Swetlow,[1] but there is difficulty in obtaining glass vessels strong enough to stand the strain. The method of drying in vacuo or in a current of gas[2] requires elaborate apparatus, is a long process for wet oils, and Swetlow (*loc.-cit.*) has proved its unreliability. Distillation with toluene[3] presents difficulty with oils containing only a small percentage of water. Bidwell and Sterling's method[4] is accurate but has three disadvantages; the apparatus should be cleaned after every two or three determinations, large quantities of a sample should be used to give a readable volume of water, and further, drops of water adhering to the sides of the condenser should be detached by mechanical means.

An interesting contribution is that of Shrewsbury,[5] who extracts the moisture from an oil with acetic acid, then mixes the extract with a standard oil and measures the critical solution temperature. This involves a correction for compounds other than water which dissolve in acetic acid.

Further methods for the determination of water in oils are given by Losana[6] and other authors.

The following method is accurate even for oils containing only a small percentage of water. A sufficient quantity of oil to give less than 0·5 c.c. water is distilled with toluene or xylene and 20 c.c. of distillate are collected in a graduated tube. Aniline is then run into the distillate from a burette until critical solution is

[1] *Neftjanoe i slancevoe Chozjajsto*, 1924, **9**, 533-537; *Chem. Zentr.*, 1925, **96**, I., 805.

[2] Philip, *J. Petr. Inst. Techn.*, 1920, **6**, 43. Marinot, *Ann. Chim. Anal. Chim. App.*, 1922, **4**, 7-8.

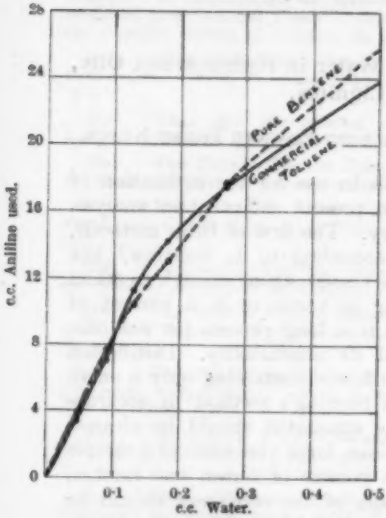
[3] Hoffman and Marcusson, *cf.* Martens, *Das Materialprüfungswesen*, 1912, 440. Dean and Stark, *Ind. Eng. Chem.*, 1920, **12**, 486. Besson, *J. Soc. Chem. Ind.*, **37**, 488A.

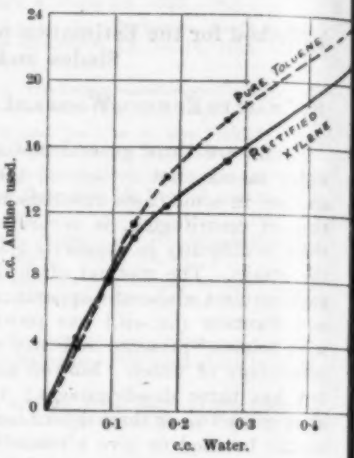
[4] *Ind. Eng. Chem.*, 1925, **17**, 174.

[5] *Analyst*, 1914, **39**, 529.

[6] *Giorn. Chim. Ind. Applicata*, **4**, 570-3.

obtained at 20° C. The number of cubic centimetres of aniline used correspond to the amount of water in the distillate, and this amount of water may be read off from determined graphs.





The graphs were obtained as follows: water was accurately measured into a 50 c.c. graduated gas measuring tube, the solvent was added to give a total volume of 20 c.c., and colourless redistilled aniline (B. Pt. 183° C.) was run in until the liquid appeared clear by transmitted light. Stirring, up and down, was accomplished with a long glass rod, flattened at the end, and the temperature was maintained at 20° C. by immersing in a thermostat. By varying the quantity of water as well as the solvent the various graphs were obtained. The following table shows the results for pure benzene (B.Pt. 80° C.), commercial toluene (B.Pt. 108·5–117° C.) pure toluene (B.Pt. 110° C.) and rectified xylene (B.Pt. 136·5–138·5° C.).

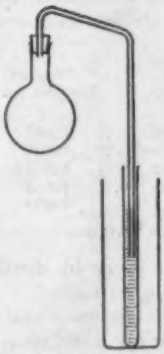
	c.c.s Aniline used.			
c.c. Water in solvent.	Pure benzene.*	Pure toluene.*	Comm. toluene.*	Rectified xylene.*
0·045 ..	3·59 ..	3·85 ..	3·40 ..	4·68
0·090 ..	7·60 ..	7·84 ..	7·51 ..	8·05
0·135 ..	10·44 ..	11·40 ..	11·31 ..	10·56
0·180 ..	13·00 ..	14·20 ..	14·00 ..	12·46
0·270 ..	17·60 ..	17·55 ..	17·57 ..	15·40
0·500 ..	25·85 ..	23·80 ..	23·72 ..	21·70

* Total volume (water+solvent)=20 c.c.

Determinations were not made with larger quantities of water than 0·5 c.c. owing to the limiting size of the graduated tube

employed. Experiments have shown that distillations giving less than 0·5 c.c. water are accurate for the estimation of water, even in wet oils—*i.e.*, a quantity of oil may be taken for analysis which gives on distillation less than 0·5 c.c. water.

The distillation apparatus first used was an ordinary 150 c.c. distilling flask fitted with a bung and a side tube two feet long. The neck of the flask was covered with asbestos paper, so that it could be heated and thus prevent the trapping of moisture. The flask containing the solvent and a weighed quantity of the oil was heated in an oil-bath, and the receiver (a 50 c.c. gas measuring tube) was cooled in ice or a freezing mixture. With this apparatus cooling was inefficient, and drops of water were trapped on the bung. The apparatus finally adopted was of the simplest type and is shown in the figure.



A flask (about 150 c.c. capacity) was fitted with a bung, boiled in toluene, and a tube, bent as shown. The receiver was *well* cooled in a cylinder containing a freezing mixture. Before each determination the apparatus was freed from all traces of moisture by distilling over about 15 c.c. toluene or other solvent.

Experiments showed that distillation with toluene or xylene brought over all the moisture from an oil of known water content, but benzene was not satisfactory. Transformer oil was dried over anhydrous sodium sulphate, filtered, and known quantities of water were added and estimated by distillation with toluene or xylene. A few results are quoted.

Pure toluene.		Rect. xylene.		Pure benzene.	
Water added.	Water estim.	Water added.	Water estim.	Water added.	Water estim.
c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
0·135 ..	0·132 ..	0·135 ..	0·131 ..	0·135 ..	0·095
0·270 ..	0·269 ..	0·360 ..	0·365 ..	0·135 ..	0·088

A point of interest was the application of the method to an inorganic hydrated salt. Finely powdered $CuSO_4$, $5\ H_2O$ was distilled with toluene and the percentage of water estimated. Since copper sulphate contains included moisture,[7] an estimation for comparison was carried out by drying at 110° C.

Method of analysis.	Amount of hydrated $CuSO_4$ taken.	Amount of water estimated.	Percentage of water.
Distillation	0·4106 g. ..	0·119 c.c. ..	28·98
Drying	1·0640 g. ..	0·3060 g. ..	28·94
Theoretical value for $4H_2O$ ..	.. .. ..	.. ..	28·85

The method has been used to estimate the moisture in crank-case, rear-axle and gear-box lubricants. The percentage of water in a transformer oil in use was found to be 0·11 per cent. Moisture in lignites and shales was estimated, and the results compared with those obtained by drying in vacuo over calcium chloride at 110° C. for 1½ hours.

Sample.	Amount taken.	Amount H_2O estim.	%	% by drying. %
	g.	c.c.		
Lignite 1	0·3316 ..	0·063 ..	18·99* ..	19·71
	0·3358 ..	0·069 ..	20·55	
Lignite 2	0·3512 ..	0·071 ..	20·22 ..	19·97
Lignite 3	0·3549 ..	0·085 ..	23·95 ..	23·70
Scotch shale	1·0012 ..	0·032 ..	3·12 ..	3·05

* These results indicate the variation limits of a series of experiments.

In each case the results given by distillation are slightly higher than those given by drying in vacuo.

A special method of estimation should be used in the case of kerosene or petrol, since on distillation with toluene or xylene some of the lower boiling fractions distil over. Since distillation with toluene cannot be used, a special curve for the sample of kerosene or petrol is determined. The oil is dried over anhydrous sodium sulphate, and a graph is obtained by adding known quantities of water. Then the amount of aniline required for critical solution with 20 c.c. of the original sample of oil is found.

Oil.	Wt. of oil taken (20 c.c.)	Amt. of H_2O estimated.	Percentage moisture.
	g.	c.c.	
Kerosene	15·826 ..	0·003 ..	0·019
Petrol	14·600 ..	0·011 ..	0·075

Estimations of moisture content by this method can be performed speedily and with accuracy on small available amounts of material.

[7] Lane and Eynon, *J. Soc. Chem. Ind.*, 1925, **44**, 150.

The Eocene Lignites and Amber Deposits of Burmah, and their Relationship to Certain Occurrences of Mineral Oil.

By Murray Stuart, D.Sc., Ph.D., F.G.S., F.C.S.

In a paper published in the Journal of this Institution, Vol. XI., No. 50, the present writer discussed the question of the origin of the oil-bearing strata of Burmah, and from consideration of the geological history of the country during Tertiary times suggested that the mineral oil now occurring in the Pegu system of Burmah was originally derived from the genus *Dipterocarpus* during the molecular replacement of the wood of the same by silica. This silicification of the wood appears to have taken place on the ancient Arakan Yoma Island, between the times of the first and second main phases of the Himalayan uplift. In the paper referred to it is shown how the oily material derived from the trees would become incorporated in the Pegu sediments, and how, after the second main phase of the Himalayan uplift, which appears to have been the main upheaval of the movement, the silicified wood would be removed from the Arakan Yomas in a gelatinous or cheese-like condition and become incorporated in the strata of the Irrawaddy system. Although, broadly speaking, the process can be divided into these two separate actions, it is only to be expected that during Pegu times occasional pieces of gelatinous silicified wood would be removed from the Arakan Yoma Island and become incorporated in the Pegu sediments, and this is in accordance with the occasional occurrence of silicified wood in the strata of the Pegu system, particularly in the upper horizons of the system. This suggestion pre-supposes the existence on the island, during Pegu times, of a profusion of vegetation consisting mainly of the genus *Dipterocarpus*. In 1916 Miss Ruth Holden published an article on fossil-wood from the Irrawaddy system of Burmah, which she named.

Dipterocarpoxylon burmense.[1] In her discussion of this wood, which seems to belong to the predominant genus found fossil in the system, Miss Holden refers to the claim of the natives of Pegu that they can recognise two varieties, *Shorea obtusa*, and the modern Engyin which she quotes as *Hopea suava*. The modern Engyin is classified now as *Pentacme suavis*, and not as *Hopea*

[1] Holden, 1916, pp. 267-272.

suava. From the nature of the fossil-wood itself the author agrees with Miss Holden in not referring it to either *Shorea*, or *Hopea*, or *Pentacme*, all of which genera belong to the tribe *Shoreae*. In naming the fossil *Dipterocarpoxylon burmense*, Miss Holden would apparently mean to include it in the tribe *Dipterocarpeae*, a decision with which the author is in agreement. *Dipterocarpoxylon* is not a living genus in the Indian Empire, the only two living genera of the tribe *Dipterocarpeae* being *Dipterocarpus* and *Anisoptera*.[2] *Dipterocarpus* is represented on the Arakan Yomas to-day below an altitude of 3000 ft. by numerous species, and forms the predominant genus of what is recognised and described in various official publications of the Indian Forest Service as "Evergreen Dipterocarp Forest." *Anisoptera* is represented in Burmah by two species, *A. glabra* and *A. oblonga*, the first of which is found in Pegu, Martaban, Cambodia and Cochinchina, while the second is found in Tenasserim. It seems unlikely, therefore, that *Anisoptera* would be represented to any extent either on the Arakan Yoma Island, or in the Shan States, or the North-East Frontier Division or Burmah during Pegu times, and the inference seems obvious that the predominant genus was either *Dipterocarpus*, or a closely allied ancestral genus that is now extinct. Since it must have flourished in Miocene times, the author prefers to classify it as *Dipterocarpus* rather than as an extinct ancestral genus, obviously very similar as regards the presence of resin ducts in the wood itself, it being almost impossible to distinguish between genera by the fossil wood only, without a knowledge of the leaves, flowers and fruit. An important fact is that although the specimen described by Miss Holden came from the Irrawaddy system and seems, undoubtedly, to belong to the predominant genus found fossil in the system, it came from the Sagaing District and was a calcified specimen, not a silicified one. It would appear to have been derived from the limestone country of the old Chinese mainland (possibly the Northern Shan States), where its formation would be due to a tree falling into one of the rivers traversing the limestone country, sinking in it, and being slowly replaced by carbonate of lime. Other than adjoining the old Chinese mainland the author does not know of any examples of calcified fossil-wood, and agrees with Theobald[3] and Oldham[4] in believing that all the fossil-wood derived from the Arakan Yoma Island is silicified and not calcified. The specimen described by Miss Holden, therefore, points to the existence of *Dipterocarpus*, or a closely allied ancestral genus, on the old Chinese mainland in Miocene times. Since the spread

[2] Brandis, 1921, pp. 64-68.
[3] Theobald, 1873, p. 8.
[4] Oldham, 1855.

of vegetation on to the Arakan Yoma Island, when it was first elevated above sea level, presumably took place from the adjacent mainland, it would appear that *Dipterocarpus* or a closely allied ancestral genus must have been common on the Chinese mainland during the period immediately preceding the time when the island was first elevated above sea level, that is to say, in Eocene times. The possible bearing of this on the nature of the Eocene lignites will become apparent below.

The lignites occur generally in the upper strata of the Eocene of Burmah (Kirthar). They occur interbedded in a typically marine series, and are themselves obviously marine deposits. Near Mawlaik, in the Upper Chindwin District, they frequently contain fossil fish teeth. From their analysis they appear to be lignites, but in places, especially where they have been involved in faulting movements, they seem to have lost much of their volatile matter, and occasionally in such cases to approximate to anthracite. They seem to extend from the Upper Chindwin in the north to the Henzada District in the south, and throughout this distance outcrop at frequent intervals along the strike of the Eocene strata. It is not intended in this paper to describe the details of the occurrences of these lignites, all that is known of which can be obtained from the publications and maps of the Geological Survey of India, but to describe certain new facts that have come to light recently concerning their composition. The lignites are generally well laminated, are jet black in colour, and do not soil the fingers when handled. When undisturbed by faulting their most striking characteristic is the high percentage of volatile matter they contain. Messrs. the Coalfields of Burmah, Ltd., have had a number of investigations carried out on the lignite from Kalewa in the Upper Chindwin District to determine the nature of this volatile matter, and have found that the result of low temperature retorting is to produce a quantity of petrol, kerosene and petroleum jelly, and a very little phenolic pitch. The Company has very kindly supplied me with the following information. In a report by C. J. Goodwin, Esq., B.Sc., A.M.I.C.E., Consulting Engineer to the Company, dated December 31st, 1923, the following analyses and results of low temperature retorting are given.

The ultimate composition of the coal was found to be :—

Carbon	68·39
Hydrogen	5·34
Oxygen	18·88
Sulphur	0·69
Nitrogen	1·94
Ash	4·76

Features of the effects of retorting were as follows :—

Volatile Matter.—The volatile matter remaining in the residue is progressively lowered by raising the retorting temperature. At

300° C. the residue contains 35 per cent. At 500° C. the figure falls to 21 per cent., and finally at 615° C. becomes 13 per cent. Oils commence to be formed at 290° C., the yield at 300° C. being about 4½ gallons per ton. The yield rapidly rises, and at 550° C. (corresponding to between 480° and 500° C. actual temperature in the coal) is 18·3 gallons per ton. The oils formed under these conditions are heavy and paraffinoid in character. On fractionation of the washed oils up to 170° C. two gallons of spirit per ton are obtained, while 5·6 gallons of kerosene distill over up to 300° C., leaving 3·5 gallons of heavy petroleum jelly. To the spirit yield must be added the spirit obtained by stripping the gas, the three gallons thus recovered bringing the total spirit up to 5 gallons per ton.[5] The products of the oil washing are about 3·8 gallons of cresylic acids, and 0·42 gallons of basic substances consisting chiefly of pyridine. There is also a little phenolic pitch, remarkable as being the only pitch produced on retorting.

Analysis of the unstripped gas was as follows:—

Carbon dioxide	20·3
Oxygen	0·2
Carbon monoxide	15·8
Unsaturated hydrocarbons	4·7
Methane and higher homologues	22·4
Hydrogen	17·0
Nitrogen	19·6

It should be pointed out that the above are the results of laboratory tests on about 5 lb. of lignite. In the same year the Company had large scale tests made on the lignite by Messrs. Rendel, Palmer and Tritton, to whom Prof. Harbord, of Messrs. Riley, Harbord and Law reported on the results of low temperature retorting, obtained from a test at Middlewich during the first week in December, 1923, as follows:—

Quantity of coal tested	24·86 tons.
Yield of crude oil per ton	18·28 galls.
Residue obtained	15·48 tons.

The crude oil obtained yielded:—

Light oil	6·03 galls.
Middle oil	6·86 galls.
Heavy oil	5·43 galls.

Testing on a large scale therefore supports the results obtained by Mr. Goodwin, and it is obvious that at a comparatively low temperature the lignite yields a large quantity of crude oil, very similar in nature to the mineral oil of Burmah. The explanation of this characteristic must be sought, presumably, from the vegeta-

[5] The author is informed by the Company that by "spirit" petrol is meant.

tion from which the lignites were derived. Since the lignites were laid down as marine sediments before the first main phase of the Himalayan movement, it would appear that the material composing them must have come from the old Chinese mainland, which included most of what is now the Shan States and the North-East Frontier Division of Burmah. It has already been pointed out that *Dipterocarpus*, or a closely allied ancestral genus, would appear to have been common amongst the vegetation occurring on the old Chinese mainland in Eocene times. One's attention, therefore, is drawn towards *Dipterocarpus* as probably having been included amongst the vegetation that provided the material that now forms the lignites. Dipterocarp wood can only be got to float with the greatest difficulty when dry, otherwise it sinks in water, and *Dipterocarpus* has the usual anatomical characters of the *Dipterocarpaceae* in that resin ducts are found in the pith of the young stem and branches, in the pith of all vascular bundles, in the petiole, midrib, nerves and veins of leaves, as well as of those bundles which run through the bark. In the case of *Dipterocarpus* they are also found in the wood, and contain an essential oil known as wood-oil.[6] Since the trees sink in water they would be eminently suitable to undergo fresh water carbonization, and the oily material contained in the trees would remain incorporated, presumably, to a large extent in the solid products of carbonization. Whether such carbonization of vegetation took place in fresh water swamps or lagoons, or in rivers, there is no geological evidence to show, but that it did take place is evidenced by the existence of the lignites. The explanation of the oily nature of the volatile matter contained in the lignites, therefore, may be that the genus *Dipterocarpus* contributed largely towards the material from which the lignites were derived. If this is so, then the nature of the oil obtainable from the lignites by low temperature distillation fits in remarkably well with the deduction already arrived at by the author that the mineral oil of the Pegu system of Burmah originated from the genus *Dipterocarpus*. In the latter case, since carbonization did not take place, but the wood was molecularly replaced by silica, the oil apparently had no solid particles to cling to and was carried away to become incorporated in the Pegu sediments, while in the lignite case, where carbonization did take place, much of the oily material apparently remained associated with the solid products of carbonization, and together with them became incorporated in the lignite seams.

The amber deposits of Burmah are more obscure. The amber occurs as smooth irregularly-shaped pieces, differing from one

[6] Brandis, 1921, p. 63.

another in size, scattered through blue Eocene clay near Maingkwan in the Hukong valley. The clay is apparently associated with a thin chalky limestone containing flint nodules and *Nummulites biarritzensis*.[7] Insects included in this amber were examined by Dr. Bather, of the British Museum, who assigned an Eocene and possibly Lower Eocene age to them. This would fit in with the evidence of the age of the including clays, since the amber, or resinous material that has since become amber, must have been formed earlier than the clays, and subsequently have been entombed in them. In a letter to *Nature* of June 3rd, 1922, Prof. T. D. A. Cockerell, of the University of Colorado, refers to the insects in this amber, and in addition to the amber from the Hukong Valley refers to specimens of pale yellow amber which he subsequently received from Mandalay containing well preserved insects all different from those identified in the Hukong valley amber.[8] Prof. Cockerell concluded that this pale yellow amber is of very recent origin, and not earlier than Pleistocene, and amongst the included insects he identified "a small bee which seems not to differ at all from the common living *Trigona laeviceps*, Smith." This led the author to point out that *Trigona laeviceps*, or as it is sometimes called, *Melipona laeviceps*, is the actual, or at least chief, source of the common resinous substance known as "dammar." These bees build in hollows within trees, crevices among rocks, etc., and line the interior surfaces of their nests with a massive resinous substance, which is "dammar." It seems to be the general opinion that dammar is constructed by the bees largely from the oil and resin of *Dipterocarpus*. The author, therefore, suggested that the pale yellow amber investigated by Prof. Cockerell may be fossil dammar, and that possibly a similar mode of origin may be attributed to the Hukong valley amber.[9] That the amber is not simple fossil resin seems to be indicated by the fact that occasionally in the Pegu sandstones small pieces of fossil resin are found which have all the characteristics of resin, and have not been converted into amber. The change from resin into amber, therefore, seems to necessitate some additional factor to mere entombment in marine sediments. The question is only of interest in the present paper, however, in that *Dipterocarpus* is introduced into the question of the probable source from which the material now occurring as amber was originally derived. It seems possible therefore that the Eocene lignites of Burmah, the amber deposits of the Hukong valley, and the mineral oil occurring in the Pegu strata, may all owe their origin to a profusion of the genus *Diptero-*

[7] Stuart, 1923, p. 404.
[8] Cockerell, 1922.
[9] Stuart, *Nature*, 1923, pp. 83, 84.

carpus, or a closely allied ancestral genus, amongst the land vegetation that existed in Eocene and Pegu times in and around the Burmah area.

The results of the investigations carried out by Messrs. Coalfields of Burmah, Ltd., on the Eocene lignites, provided a simple explanation of certain anomalous occurrences of mineral oil and gas in Burmah, for which a satisfactory explanation has not been forthcoming hitherto. In certain localities, particularly in the Minbu and Thayetmyo Districts between Lat. 19° 35′ N. and Lat. 20° N., oil see pages occur at intervals along the main Eocene-Pegu junction, occurring sometimes in the Eocene strata and sometimes in the Pegu strata. They do not conform to any definite geological horizons, but seem to occur in a more or less haphazard way both above and below the junction of the two systems. In addition to these oil seepages, and about three and a-quarter miles west of the Yenanma oilfield, there is a line of mud volcanoes. Occasional emanations of gas also occur without apparently appertaining to any definite geological horizon. The Yenanma oilfield itself also exhibits very unusual features, which have never been explained satisfactorily hitherto. The field is situated on rocks belonging to the Pegu system, and is situated some mile and a-half east of the Eocene-Pegu junction. The Pegu strata are all dipping remarkably uniformly in a general east-north-easterly direction at an angle of about 20°. There is no surface evidence of either anticlinal or terrace structure, the strata of the Pegu system forming an apparently undisturbed monocline. When oil was first obtained at Yenanma by drilling, it was assumed that the oil would be found to occur in definite oilsands in the Pegu series, and that once one of these oilsands was located, it would be possible to drill wells along the strike of that sand and obtain oil from it. Actual drilling soon proved, however, that such is not the case, and that the presence of the oil has little, if anything, to do with the dip and strike of the beds outcropping on the field. The depths at which the principal wells obtained production can be grouped into a more or less horizontal plane, while the strata are dipping at about 20°. The oil wells themselves on the field are grouped in a narrow strip arranged approximately at right angles to the strike of the strata, the central wells yielding oil and being dry as regards water, the wells on both edges of the narrow strip yielding less oil and varying amounts of water from the same geological horizons that wells inside the strip and only one hundred and twenty feet away yield oil and no water, and wells located along the strike of the strata outside the narrow strip yielding only water. Another remarkable feature that soon became evident was that the productive area showed no signs of diminution in size as a result of

oil being extracted from it. In other words, there was no observable encroachment of water laterally, along the strike of the strata, into the producing area. The gas pressure also seemed abnormal

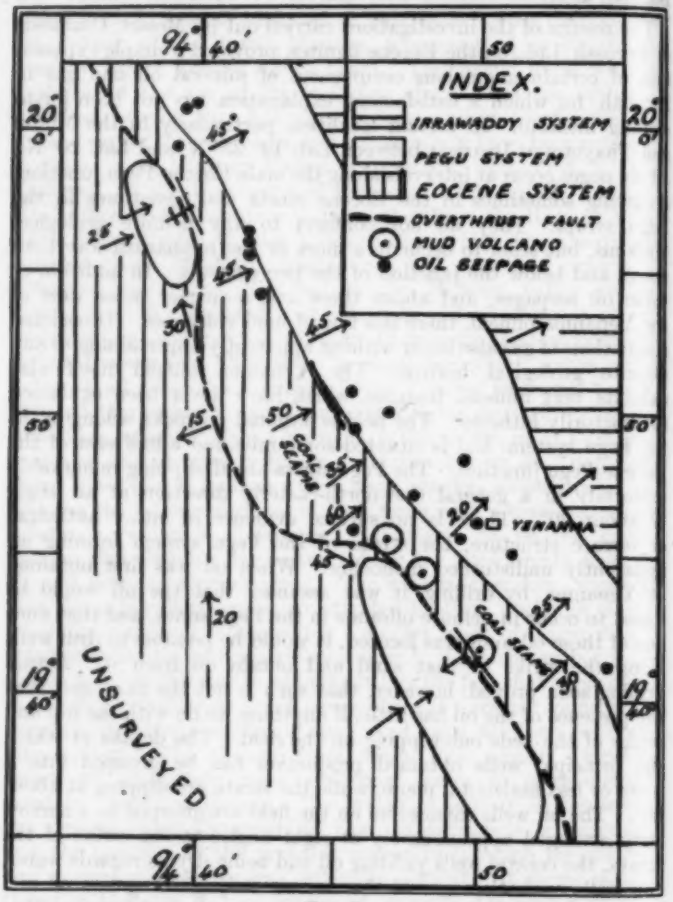


FIG. 1.
SKETCH MAP OF THE GEOLOGY OF PARTS OF THE MINBU AND THAYETMYO DISTRICTS.

for simple monoclinal structure. Wells when first drilled in and allowed to stand, filled up to the casing head and then in some instances occasionally spouted until all the oil was blown out of

the well, in other instances the wells did not spout but flowed slowly. While wells were being drilled there have been instances of the bailer, which was hung in the top of the casing for the night, being blown out of the well. The gas yield of the wells remained remarkably constant, and there is, and always has been, more than sufficient gas to pump the entire field by means of central pumping power plants operated by gas engines. The oil produced by the field is not a bituminous oil, and also the wells on the field do not seem to become paraffined up to any appreciable extent, consequently, in view of the simple monoclinal structure indicated by the surface geology of the Pegu rocks, it was difficult to see how there could be any sealed structure in which oil and gas could be retained under pressures such as drilling on the field indicated. Geological mapping of the country surrounding the field subsequently established what the author had suspected, namely, that in this portion of the Minbu and Thayetmyo Districts the rocks have been affected by an overthrust fault of considerable magnitude. This overthrust has come from the east towards the west, and the thrust plane cuts the surface some miles to the west of the Eocene-Pegu junction. The overthrust is evident not only from the curvature of the fault-line, or outcrop of the fault-plane at and from the contortion of the strata occupying a frontal position in the overthrust portion, but in places, especially some four miles south west of Yenanma, brecciated fault-rock forms the approximately horizontal floor of the stream beds. The thrust appears to have occurred towards the end of the third and last main phase of the Himalayan movement, and to be subsequent in age to the main folding of the rocks of the country. Immediately to the west of the fault-line there is a line of synclines of Pegu rocks forming outliers in the Eocene territory. Two of these synclinal outliers are shown on the geological sketch map given in Fig. 1. These synclines of Pegu rocks appear to have offered more resistance to the overthrust than the intervals between them did, and to have formed buttresses against which the overthrust strata were crumpled and contorted much more than was the case in the intervals between them. Against the southern syncline shown on the sketch map the overthrust strata are crumpled and contorted to a width of over three-quarters of a mile, and throughout this width the strata show a general vertical dip with minor contortions and isoclinal folding. It is probable that the vertical strata as a whole represent much denuded isoclinal folds. An overthrust that would crumble up the strata occupying a frontal position in the portion overthrust and compress them into a band of isoclinal folds three-quarters of a mile in width, must represent a very considerable overshift and must represent one of the most important

tectonic features of that part of the country. As soon as the existence of this overthrust and its magnitude were established it became evident that it must extend under the Yenanma field. It also became evident that oil either incorporated along, or finding its way along, a channel in the trace of the thrust-plane would explain the unusual features exhibited by the field. The proof that oil, similar in nature to the mineral oil occurring in the Pegu system of Burmah, is easily obtainable from the Eocene lignites, affords a ready explanation of the origin of the oil obtained in the Yenanma field and occurring in the numerous seepages along and adjoining the main Pegu-Eocene junction in that part of Burmah, since the Eocene lignites must have been affected by the overthrust, and where so affected might be expected to have given up much, if not all of their volatile matter. It also affords a ready explanation of the existence of the mud volcanoes and numerous gas emanations that occur in the vertical strata adjoining the fault line south-west of Yenanma. Fig. 2 shows a diagrammatic geological section east-north-east and west-south-west through Yenanma. No attempt has been made to draw this section to scale, since the amount of the overshift of the fault is not known. It is obvious that where the trace of the overthrust fault is only at a

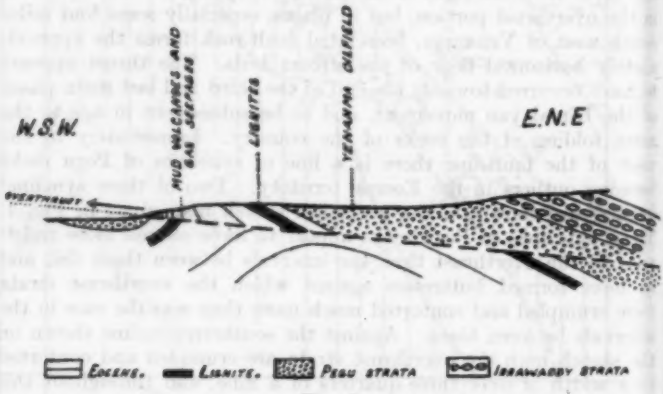


FIG. 2.

DIAGRAMMATICAL GEOLOGICAL SECTION E.N.E. AND W.S.W. THROUGH THE YENANMA OILFIELD.

comparatively small depth beneath the surface, oil derived from the lignites in the neighbourhood of the fault trace could find its way to the surface, through fractures or joints or minor faults in the overlying strata, or possibly by soaking through porous

strata, and this would account for all the anomalous seepages of oil along and near the Pegu-Eocene junction. Where the trace of the fault is at a greater depth beneath the surface the oil and gas could remain strung out, along the trace of the fault, or be finding its way along it through irregular channels towards the seepages, and the presence of one of these channels would explain both the presence of oil below the productive strip on the Yenanma field and its unusual distribution. The mud volcanoes appear to be related to the lignite horizon that should normally underlie the synclinal Pegu outlier, the crumpled strata of the overlying overthrust portion of the country making the escape of gas and mud comparatively easy. The same reasoning applies to the gas emanations, nearly all of which occur in the contorted area. The seepages of oil near the Pegu-Eocene junction, and the mud volcanoes, in the portion of the Minbu and Thayetmyo Districts under discussion, and the oil under the Yenanma oilfield, therefore, all seem to be due to the fact that the Eocene lignites have been affected by the overthrust and have yielded up some of their included oil and gas. This being the case, it would seem that occasional traces of lignitic material should occur strung out along the trace of the overthrust, and it is a significant fact that in three wells in the Yenanma field black lignitic material has been encountered at approximately the horizon of the presumed overthrust fault plane. The oil and gas in the seepages under discussion and the mud volcanoes, and the productive oil of the Yenanma field, therefore, would appear to differ in mode of formation from the ordinary mineral oil of the Pegu strata of Burmah in having been derived from the Eocene lignites after the Pegu strata were deposited and not being part of the oil originally incorporated in the Pegu strata. The similarity between the two oils would be explained if both were originally derived from the wood-oil of the genus *Dipterocarpus*, as has been suggested by the author. Oil can therefore be expected along the trace of the overthrust throughout the distance of the overshift of the lignites, but experience in drilling has shown that it does not occur uniformly distributed throughout the fault plane, but occurs along irregular channels in the fault plane. The fact that from January 1st, 1922, to July 31st, 1925, the Yenanma oilfield has produced 141,572·5 barrels of oil, and is a Star Machine proposition, shows that there is a hitherto unsuspected valuable quantity of oil incorporated along the trace of the overthrust fault. The location of similar fields, however, must depend almost entirely on the results of experimental drilling, as little help can be obtained from the surface geology. From the facts that have come to light in the Yenanma area, the author is convinced that the mud

volcanoes of the Henzada District of Burmah,[10] and the mud volcanoes and oil seepages of the Nam Chik area in Upper Assam, similarly owe their existence to lignites being affected by faults, as do probably most of the oil seepages adjoining the Pegu-Eocene junction in the Upper Chindwin.

In 1910 the author recorded the fact that the oil bearing horizon of the Pegu system in Lower Burmah appeared to be the Kama clays, and that the underlying Prome sandstones and Sitsayan shales were not oil-bearing.[11] This would be quite in accordance with the origin of the oil-bearing strata of the Pegu system suggested by the author in the previous paper referred to above, since, when the Arakan Yoma Island was first elevated above sea level, it would take some little time for profuse forest growth to spread all over it, and one would expect a thickness of Pegu strata to be deposited before the silicification of trees on the Arakan Yoma Island commenced to supply oil in any quantity to the Pegu sediments. Attributing the oil occurring as seepages near the Eocene-Pegu junction to the Eocene lignites separates it geologically from what may be termed the main oil measures of the Pegu system, and makes it a distinct geological problem.

The author's best thanks are due to Messrs. Coalfields of Burmah, Ltd., for supplying him with the results of their investigations; to Messrs. Indo Burma Oilfields (1920), Ltd., for permitting him to mention in general terms the structure and peculiarities of the Yenanma oilfield; and to Messrs. W. J. Dunstall and D. L. Kirkpatrick, who ably assisted him in field mapping in the neighbourhood of the overthrust fault line.

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[10] Stuart, 1912, p. 261 and map.
[11] Stuart, 1910, pp. 265, 276.

The Origin of Hydrogen Sulphide in Persian Natural Gas and a Method of Preparing Unsaturated Hydrocarbons.

By W. H. Cadman, B.Sc., A.I.C., F.C.S.

Professor de Böckh, during his visit to the oilfields at Maidan-i-Naftun, in May last, suggested as a research problem of great interest to petroleum geologists a study of the action of hydrocarbons on gypsum in the hope that such an investigation might throw some light on the origin of sulphur in petroleum. His personal experience of various oilfields in the world was that sulphur is invariably found in considerable quantity when the oil is obtained from a dolomitised limestone of lagoon formation, provided gypsum also occurs in or near the main limestone.

On the other hand he had noticed that oil obtained from sands in the absence of gypsum contained little or no sulphur.

He described a natural gas found in a certain well in the Hungarian oilfields which contained no trace of hydrogen sulphide, while a leakage of the gas through a clay and gypsum formation a short distance from the well contained a definite percentage of hydrogen sulphide.

The Persian oilfields are remarkable for the high percentage of hydrogen sulphide in the natural gas. The low pressure gas from the gas separating tanks through which the crude oil passes contains at present from 12 to 13 per cent. of hydrogen sulphide. The reservoir rock or Asmari limestone of the Persian oilfields contains enormous quantities of hydrocarbons overlaid by the Lower Fars series, which include large amounts of chemical deposits, including gypsum, and partially by the Middle Fars, which also contains a few bands of gypsum.

The innumerable hillocks of gypsum (locally called "gatch") form the most striking surface features of the oilfields at Maidan-i-Naftun.

Elemental sulphur is also found in the neighbourhood of Maidan-i-Naftun and was in fact until recently a local industry, the refined sulphur being sold in Schuster for the manufacture of gunpowder. It was decided to try the effects of petroleum hydrocarbons on sulphur and subsequently on gypsum.

1.—Hydrocarbons and Sulphur.

Experiments were made to find the effects of heat on mixtures of sulphur with Maidan-i-Naftun crude oil and the various constituents of crude oil previously deprived of all traces of hydrogen

sulphide. In every case hydrogen sulphide was obtained. Even Persian Natural Gas, from which every trace of hydrogen sulphide was removed by passing it through sodium hydroxide and cadmium chloride solutions, when passed over heated sulphur gave a copious evolution of hydrogen sulphide. This is not in accordance with the statement made by Day in his handbook of the Petroleum Industry, Vol. I., p. 529, that "sulphur reacts very slightly on the lighter paraffin hydrocarbons even when heated, while Engler and Spanier have shown that hexane is not attacked by sulphur at the boiling point, and there is only a perceptible evolution of hydrogen sulphides at 210° C."

In point of fact a well-known laboratory method of obtaining pure hydrogen sulphide consists in heating paraffin wax with sulphur, when a copious evolution of the gas takes place. This reaction stops on withdrawing the source of heat.

Although elemental sulphur occurs in considerable quantity in certain localities at the oilfields, it is far too limited to account for the high percentage of H_2S in Persian Gas.

The results obtained above agree with the general statement made by Dr. F. B. Thole in his paper on "The Chemical Nature of Petroleum" on p. 215 of the Petroleum Industry, 1920 (Inst. Pet. Tech.): "If various hydrocarbon fractions of petroleum are heated with sulphur to a temperature of 200° C. or upwards, dehydrogenation occurs, the products being hydrogen sulphide and olefines."

2.—Hydrocarbons and Calcium Sulphate.

Another possible source of the sulphur is the very extensive gypsum formation above the main limestone. In this the sulphur is present in the stable compound, calcium sulphate, $CaSO_4 \cdot 2H_2O$. Below this and immediately overlying the oil bearing Asmari limestone there is always found a zone of anhydrite.

The experiments previously made with the petroleum products of sulphur were repeated, using calcium sulphate in place of sulphur. The calcium sulphate was used in the form of (1) gatch (unburnt), (2) anhydrite from well borings, and (3) pure gypsum. In each case hydrogen sulphide gas was evolved, being detected by the usual means.

Much has been written concerning the possible origin of sulphur in petroleum, but *the fact appears to have been overlooked that the hydrocarbons of crude oil and natural gas all react with calcium sulphate at moderate temperatures with evolution of hydrogen sulphide.*

The high pressure natural gas deprived of H_2S by passing through wash bottles containing caustic soda and cadmium chloride was tested for H_2S before and after the experiments. The effect of

this sulphur-free gas on the heated silica tube and asbestos packing was demonstrated, and also the effect of heating the calcium sulphate alone in the absence of the gas. Having proved that no trace of hydrogen sulphide was formed by any combination of the materials or apparatus employed the sulphur-free gas was passed slowly through the silica tube containing (1) gatch and (2) anhydrite heated to dull redness. Hydrogen sulphide was almost immediately evolved and detected without difficulty.

Prof. Hugo de Böckh's careful observations on the association between a high sulphur content of the oil and the presence of gypsum are thus experimentally accounted for. They are the natural results of the chemical reactions between the oil hydrocarbons and calcium sulphate.

As the high pressure gas yields the bulk of its hydrogen sulphide to the accompanying oil, the presence of sulphur in the crude oil is thus accounted for.

It has already been shown that when pure methane is passed over powdered gypsum heated in a tube, in addition to hydrogen sulphide, steam, carbon dioxide and an unsaturated hydrocarbon gas are evolved and a mixture of calcium oxide and calcium sulphide remains.

The reaction is therefore not by any means the simple one suggested by Hoppe-Seyler :—

$$CaSO_4+CH_4=CaCO_3+H_2S+H_2O.$$

Quantitative tests are now in progress and the products obtained by heating natural gasoline, petrol, kerosene, etc., with calcium sulphate will be examined.

Obscuring of Oil Indications in Rotary Drilling.

By Alexander Duckham, F.C.S.

Frequently a rotary outfit drills through an oil-bearing sand without there being any indication of oil in the returning mud, and yet, when the level of mud in the hold is reduced, the sand gives good production. This is generally attributed to the fact that the mud at the point of cutting is not only under a pressure due to the depth of its column, which is at least equal to the pressure behind the oil, but in addition such pressure is increased by the pressure exerted by the pumps.

Certainly this accounts for prevention of access of oil from the walls of the hole, but does not account for the absence of any indication of oil or fluorescence, which would be expected from that column of the sand which is actually cut out and disintegrated by the bit and passes into the circulating mud.

Investigation of this phenomenon in Trinidad revealed that some muds have the property of absorbing crude oil even to the extent of 20 per cent. by volume without giving any evidence of its presence when in motion; indeed, even when standing quiescent in the sumps. This is evident if the mud and oil be shaken together in a glass bottle and allowed to stand.

Taking the instance of a 15 in. hole drilled to take 12 in. casing, a column 2000 ft. deep means a volume of some 15,000 gallons, and there may be as much mud again in circulation in the sumps, so that the total will be some 30,000 gallons, whereas, on the other hand, the volume of oil in 50 ft. of sand having a 25 per cent. oil capacity is somewhat less than 100 gallons, or equal to ·06 per cent. of the volume of mud.

Therefore the absence of any indication of oil in the "returns" is not astonishing. It is also noticeable that any gas which comes to the surface, when such mud is employed, is odourless. Examination of the clays or clayey shales from which these muds are mixed shows that when they are roasted and powdered they have the property of decolorizing and deodorising oils. This explains the odourless gas—for such gas has to rise through a comparatively confined annular space, say, 2000 ft. in length, and so has mixed very intimately with the mud.

The composition of the clays is being investigated, and its effect on oil and gas both when roasted and in the form of mud, is being more closely examined in the laboratory, but in the meantime it appears advisable to publish, for the interest of those concerned, the facts as determined to date.

Notes on Rotary Drilling.

By Cyril W. Davson, A.M.I.Mech.E.

1. *Building Derricks and Rigs.*—Where steel derricks, which are designed and standardised to suit various purposes, are used, no problem presents itself, but timber derricks can be constructed for any height and with any size of base.

It is perhaps a good standard to lay down that no rotary derrick should have a base of less than 22 ft., because one of the principal functions of a derrick floor is the stacking of pipe or casing, usually in lengths of three or four joints. If the derrick floor space is insufficient, the drill-pipe or casing when temporarily removed from the hole has to be "broken down" and "made up" again when required, resulting in waste of time and labour, extra wear and tear on the threads, and its not being ready for immediate reinsertion in the hole when required.

The height of a derrick to take three joints of casing should be about 95 ft., and to take four joints, say 112 ft.

Where possible the four corners of the derrick should be on concrete, and it is of the utmost importance that derricks should be properly aligned.

The Rig.—It is important that the drilling engine should be solidly bedded and tied down in some suitable way, as otherwise it will constantly be getting out of alignment, the chain drive will be breaking, and the driller will be incessantly engaged in repairing breakdowns which should never occur.

The Draw-works. Practically all line shafts eventually bend somewhere close to the line shaft engine sprocket, obviously due to the fact that the maximum bending moment is at this point. Another jack post should be introduced here, or makers should increase the diameter of their line shafts at this portion of their length.

2. *Twisting Off.*—It is now an accepted fact that 10-thread type is not suitable for "rotating on," and 8-thread pipe is now made in all sizes for casing wells and for "drilling-in strings." This considerably reduces the risk of twist-offs, but of course by no means entirely eliminates it.

Sudden "heaving in" from below due to gas pressure, or caving from above, may grip the drill stem and cause a twist-off before the fact can be appreciated by the driller, but the new differential rotary tends to provide for even these sudden emergencies, as it

adjusts the feed to variations in bit pressure, and thus greatly minimises the risk of twist-offs so prevalent with hand-fed bits.

3. *Sizes of Casing.*—If a 12 in. water-string is to be set, then it is advisable to use a 17 in. surface casing. If a 10 in. water-string is to be used, then 15 in. surface casing will suffice.

To set a 12 in. inside a 15 in. string is inadvisable, because in drilling the 12 in. hole a bit cannot be used that is big enough to prevent the 12 in. shoe from cutting off the plastered walls, and thereby caving is caused with all its attendant difficulties.

If a 17 in. surface conductor or casing is set, the first water-string could be 12 in., and the next string will then be 8 in. or, if available, possibly 9⅝ in.

These figures are, of course, merely intended as guides to demonstrate the principle, modifications must naturally be made to suit special conditions.

4. *Freeing Casing.*—When a string of drill-pipe is frozen, washing down outside the string with a string of casing, an overshot and rotary shoe may prove effective. It is sometimes necessary to wash down inside the frozen string through perforations, and possibly outside also.

Briefly stated, freeing casing with the rotary is accomplished by washing down either inside or outside the frozen string, or both, with other strings. The overshot enables the casing to be gripped and pulled the moment it is freed, and the rotary shoe permits the wash-down string to rotate its way through the binding material, so that the overshot can grip the frozen string at the lowest point.

Hydraulic jacks may be required to aid in pulling the lost string.

If all efforts fail, then it may be necessary to resort to "backing-off" the string with left-hand pipe; this usually ends in fishing for the last few joints, which may have to be side-tracked.

5. *Shutting-off Water.*—This is done by casing it off, the water-string being usually cemented, but mechanical difficulties may at times prevent successful cementation, and then a string of casing with a lead shoe has to be inserted to make a seal.

On soft formation this would probably prove of little avail, but on hard formation it is an effective substitute for cement and has the additional advantage that, on drilling deeper, this string, if freed, can be lowered and dumped again. This has the two-fold advantage of not only saving the cost of another string, but of still retaining the larger hole. "Keep the hole as large as you can, as long as you can," is a wise maxim.

At times casing is dumped and a formation cut off must then be relied on. Nothing, however, is really so dependable and

satisfactory as a sound cement job. But whatever means is used to shut off the water, the water-string after dumping should be lifted until it is completely stretched out. The practice of dumping a long string of casing without stretching it and clamping it at the top of the string is bad.

Oil Field Waters must be constantly tested, as they are of the greatest value in localising and comparing the various water sands.

6. *Fishing.*—This in rotary work is usually concerned with recovery of lost pipe. A long-tapered tap, or male and female dies, may be used or a bull-dog spear. These may be classed together, because once a hold has been taken there is no definite means of getting clear should it be found impossible to pull the lost joints.

Then there are trip spears and the Mack spear. This latter is excellent, as, when necessary, by merely rotating to the right the spear disengages and can be pulled out.

Washing over the lost joints, as previously explained, is another method.

If a great many joints have been left in the hole, backing off with the left-hand string and left-hand taper tap may have to be resorted to.

Finally, if all other methods fail, side-tracking may be necessary, and this is accomplished by drilling first with diamond point bits and then following up with fish tails.

Sometimes it is found that no fishing tool will act, and this probably means that the top of the lost joists is badly damaged or burred over. A milling cutter must then be used, and is run by the rotary itself on the bottom of a string of drill-pipe.

All this shows the urgent necessity for an adequate workshop, without which little, if any, rotary drilling should be undertaken. This workshop should be backed up by a complete set of stores.

7. *Making Hole.*—The modern rotary in the hands of really skilful operators may be regarded as a highly efficient machine. Two or three hundred feet under favourable conditions can be accomplished in twenty-four hours, and possibly a thousand feet within a week. The making of hole is usually the least of all difficulties, and the best hole-maker is not always the best all-round driller.

The best driller is he who can keep out of all the evitable difficulties and find a way out of all the inevitable. This requires not merely skill, but dogged determination. The speed at which hole can be made is practically governed by the formation.

Breaking records is difficult and effects no material economy, whereas breaking drill-pipe and other gear is very expensive, and may possibly end in long and unsuccessful fishing jobs.

8. *Coring.*—Most practical operators with the rotary look for the simplest devices, and therefore at first sight the single core barrel may appear more attractive than the double core barrel, because in the former nothing can go wrong. It is simply a short piece of pipe with teeth or prongs about 1 ft. long cut on the end of it. The prongs cut the core and afterwards, by a slight jar, hold it in place. But the fact may be overlooked that the mud flush contaminates the core on extraction from the hole. The double core barrel allows free circulation of the hole during coring and prevents contamination of the core during extraction from the hole. False hopes are sometimes raised by the contamination of cores by lubricating or other oils.

Sampling with the rotary is still a somewhat difficult matter as the core barrel must take the torsion, and therefore a distorted and fictitious angle of dip may be expected, although, of course, the actual sample of the material should in most cases be reliable.

It has, however, been reported that with the single core barrel certain samples have been liable to metamorphic changes of their minerals owing to the heat generated. On the other hand, relying on "returns" solely for geological information would be like clutching at a straw, as all sorts of mechanical interferences are at work.

To core is also at times risky ; for example, when it is believed that a pay sand is approaching, as the sand may contain heavy gas pressure. From the mechanical point of view coring is always undesirable, as it means pulling out the drill-pipe and reinserting it.

Both these above-mentioned troubles may, however, be partially overcome at some future date by the new collapsible bits and core barrels which may be used in conjunction with same, and progress in this direction is already being made.

9. *Testing.*—Briefly summarised, the salient features in testing with the rotary would be somewhat as follows: Set conductor string, then water string, and having cased your hole to just above the believed pay sand, drill on cautiously with drilling-in string, watching returns carefully. If signs of sand appear and there is practically no gas pressure—*i.e.*, if safe, core. If not, proceed with drilling. If heavy gas pressure is struck it must be cautiously relieved under control, possibly on the outside of the drilling-in string through the blow-out preventer, but this should not be allowed to continue longer than is necessary, as it is liable to injure the 6 in. string by cutting the collars and also the contiguous water-string.

If no gas pressure is struck and no apparent signs of oil show in the returns, it does not follow that there is no well. In either case endeavour to remove the wash pipe as soon as possible, and, if it has been decided to make a test, circulate with clear water for

36 hours, more or less, until the returns are clear, watching carefully for traces of oil. Baling and swabbing, or by putting a vacuum on the well, by pump suction or other means, may be necessary, as the oil, if any, may have receded back in the strata owing to the previous flush pressure. If all reasonable efforts prove unavailing, the drilling proceeds again after the hole has been mudded up, and the same process is followed for each succeeding test, but with increasing mechanical difficulties and dangers each time.

The difficulties of making several tests in the same hole in caving strata with the rotary will now be obvious, for in caving and difficult formation skilful and patient work has been done if two or three tests have been made in the same hole, even if it is then not feasible to make further tests and the hole has to be abandoned. In this case another well can be offset and rapidly drilled down and testing continued in the new hole.

Drilling in for "tests" should only be done in the morning, as a well might come in during the late afternoon, greatly adding to the difficulties of control and enhancing the dangers of fire during the hours of darkness.

10. *Bringing in a Well.*—A modern drilling-in string is usually made up of 6 in., 23½ lb., 8-thread, special rotary drill-pipe. On the top of the string there are a few threads of inserted pipe which works in a stuffing box between the rotary table and the blow-out preventer; this ensures complete control in the event of heavy gas-pressure accompanied by sand at high velocity being encountered.

On the bottom of the string the last few joints are perforated—*i.e.*, one or more joints. This is of course to permit the oil to pass through, but sand and similar material must be prevented from stopping circulation. This is achieved by inserting inside the 6 in. string a 2 in. pipe, which runs the whole length of the perforated pipe. The mud flush can thus circulate through this pipe to the bit without interference from sand or other material which is forcing its way with the oil through the perforations. This pipe is termed the wash pipe.

Between the bottom of this wash pipe and the bit is a back pressure valve; this is to prevent the gas pressure forcing its way up, stopping circulation, and possibly damaging the hose.

It is a usual practice to place another back pressure valve much higher up the string in case of accidents. The bottom back pressure valve is made of steel, but the top one must be of cast iron, because it has to be broken in order to pull out the whole wash pipe when the well has been drilled in, in order to allow the oil to flow freely through the perforated joints up the drilling-in string and

out through the flow lines into the flow box and thence to be pumped away to the flow tanks.

On the last joint of inserted pipe at the top of the drilling-in string is the master gate valve, and directly connected to this is the bottom flange of the four-way cross, to the top flange of which is connected the crown valve, and to the two side flanges are connected the flow lines. Into one or both of the flow lines is introduced a solid steel plug with a hole say $\frac{1}{2}$ in. diameter more or less, and this is called choking or beaning down the well.

The amount to which a well should be beaned down can only be found empirically; it depends on the nature of the formation, and here great importance must be attached to using the right amount of perforated pipe on the bottom of the string, which is also an empirical problem.

Insufficient perforated pipe does not allow free access for oil in certain formations; on the other hand, too much perforated merely allows impervious strata to force its way in through the top joints and stop the flow of oil by cutting off the oil sands.

No alteration of the choking at the top of the string will rectify too much or too little perforation on the bottom of the string.

11. *Personnel.*—Rotary drilling operations cannot be conducted on efficient lines unless an adequate staff is provided, as a constant interchange of tools, etc., is taking place all day between the rigs and the stores, which must be under the supervision of a superintendent driller and storekeeper, and the former must be absolutely expert in rotary work.

Estonian Oil-Shale.

In his written reply* upon the discussion regarding Estonian shale, Mr. P. N. Kogerman raises several interesting points.

He is evidently not very familiar with low temperature distillation, otherwise he would not follow the fetish of complete extraction as against the production of high quality oils. When complete extraction is aimed at, as in the Scottish retorts, successful commercial results can only be obtained when there is a large production of ammonium sulphate. With Estonian shale this does not seem to be possible. In low temperature processes it is found that the last 8 to 10 per cent. of volatile in the shale is not worth extracting. It gives more gas than oil, and it necessitates working at too high a temperature to give a crude oil of high quality. These are facts that have been proved by innumerable large scale retorting tests. We know now from the latest experiments that it is possible to extract 30 per cent. from Estonian shale as light crude oil at very much lower temperatures than 450 C., and at the same time leave enough in the residue to be able to utilise it as a fuel. It is along such lines that we must look to get the best commercial results from such a difficult material as kukersite. A crude oil of 0·83 gravity can be made with an extraction of 30 per cent. or perhaps even more. It was because I was familiar with these recent experiments that I made the somewhat sweeping statement that the oil being produced in Estonia from kukersite was of too poor a quality to put the industry in a really favourable light. No doubt there is much experimental work still to be done on the subject, but we know now what can be done, and all that remains to do is to prove on a commercial scale that such results can be obtained. Much that has been written on the subject is, as Mr. Kogerman states, quite out of date and not very reliable, but the results that I have indicated above have actually been obtained, and I believe will soon be obtained on a commercial scale.

E. H. Cunningham Craig.

* Ibid, xi., 50, pp. 231–233, June, 1925.

STUDENTS' SECTION, LONDON BRANCH.

A RÉSUMÉ of the paper read before the London Branch of the Students' Section on April 21st is given below :—

Automobile Engine Design in Relation to the World's Fuel Supplies.

By E. L. BASS (Associate Member).

THE greatest demand for liquid fuel originates from the automobiles of the world, and the rate of increase of these compared to that of petroleum production is not encouraging for the future outlook of plentiful supplies of motor fuel at reduced prices. Alternative methods for reducing the widening breach between supply and demand for motor fuel are suggested, and need the careful consideration of automobile engineer and petroleum technologist alike.

The Demand for Motor Fuel.—The following table shows the total number of motor vehicles in the world, together with the world's production of crude petroleum since 1912.

Year.	Number of Motor Vehicles in the World.	World's Production of Crude Petroleum. Barrels.
1912	1,360,000 ..	352,447,000
1913	1,685,000 ..	383,547,000
1914	2,223,000 ..	403,745,000
1915	3,100,000 ..	427,740,000
1916	4,380,000 ..	461,493,000
1917	6,200,000 ..	506,703,000
1918	7,075,000 ..	514,729,000
1919	8,800,000 ..	545,126,000
1920	10,980,000 ..	693,196,000
1921	12,830,000 ..	759,030,000
1922	14,910,000 ..	854,809,000
1923	19,190,000 ..	1,010,995,000
1924 (estimated) ..	20,380,000 ..	1,013,010,000

From the above we see that in 1912 there were 259 barrels of crude available per automobile, whilst in 1924 that figure had dropped to 50.

In 1912 the average yield of petrol was 10 per cent. of the crude refined, yet in 1924 we find it to be as high as 28 per cent. Even

with this increase, we only get 560 gallons of petrol available per automobile in 1924 against 1,040 gallons in 1912.

Specification and Properties of Motor Fuel.—It is essential that fuels for engines fitted with carburetters should have certain properties falling within well defined limits. These limits are set by manufacturer, designer, and the automobile user. For example, the manufacturer decides whether the type of engine is to utilise a light or heavy fuel (petrol or kerosene) or both. The designer calculates the power output of his engines from the heat contained in the fuel, and also has to consider the "detonating" or "pinking" property of the fuel, which fixes the useful compression pressure at which the engine will work. Finally, the automobile user imposes further limitations, in that he calls for a fuel that is reasonable in first cost, convenient to handle, economical in use, and which will give easy starting. All these demands are dependent upon the question of plentiful supplies, and it is this factor which has more bearing upon the fuel specification than any other.

To appreciate the full value of these limitations, it is important that the relative values of certain chemical and physical properties of motor fuel should be known, and in this discussion petrol-driven, and not kerosene-driven, vehicles will be considered.

The volatility, the measure of which is the vapour pressure, the pressure created by the vapour formed at a given temperature, will be examined first. A high vapour pressure is desirable since the fuel producing the highest pressure must obviously form the greatest amount of vapour.

A property closely connected to the vapour pressure is the distillation range, the range of temperature necessary to completely evaporate the fuel.

It will be apparent that the "end-point," the temperature at which the last drop is distilled over, will give an indication of the case with which the heaviest portion of the fuel may be vaporised.

The next property to be considered is the tendency a fuel possesses to detonate in the engine cylinder. This characteristic does not apparently hold any definite relation to the known chemical and physical properties of fuels, although it was at one time thought that the spontaneous ignition temperature was a function of the behaviour of the fuel in the engine. It should be noted that the spontaneous ignition temperature is that at which the fuel self ignites, without the application of flame or spark to the vapours formed.

In this connection, reference should be made to the work of Ricardo, who designed a special high speed engine with variable compression adjustment, by means of which it is possible to determine the exact compression ratio and pressure at which a fuel

detonates. It should be noted that the detonating value of a fuel depends very largely upon the engine in which the experiment is conducted. In the case of the Ricardo engine, the conditions with respect to the shape of the combustion chamber, valve design, cooling, etc., are as nearly ideal as possible, so that "detonating values" determined in it are comparatively high.

Numerous experiments conducted in the Ricardo laboratories have shown the spontaneous ignition temperature to be only a very approximate indication of the tendency of a fuel to detonate, so it would be unreliable to consider that any relation existed between the two.

Meeting the Demand.—The methods adopted for increasing the petrol fraction are interesting, and they have an important bearing upon the properties of the product supplied to the public.

(*a*) *Increasing the distillation range.*—The first method adopted, and the most obvious solution to the problem, was the continuation of the distillation period so that fractions of higher boiling-point were included with the initial, and very low, boiling-point fractions. We have seen that as a high end-point entails low vapour pressure, high boiling-point fuels are unsuitable for use in engines fitted with carburetters.

(*b*) *Cracking.*—With the rapidly increasing demand for motor fuel, the "cracking process" was more intensively adopted, until to-day we find that a considerable proportion—estimated at 15 to 20 per cent.—of the total motor spirit is produced by this process.

It is found that the maximum amount of cracking economically possible varies for the different crudes. Crudes with too great a content of asphaltic matter do not lend themselves to cracking to any great extent because they deposit excessive quantities of carbon during treatment.

(*c*) *Natural gas petrol.*—Wherever possible natural gas is brought under control and treated for the recovery of its valuable liquid constituent.

There are two principal methods of recovering petrol from natural gas, viz., the "compression" and "absorption" methods. Of these, the former is the more widely used at present, although it appears probable that it will be superseded in the future by the absorption method, which has a wider scope and greater efficiency.

In the compression method the gas is subjected to a fairly high pressure, and the heat thus generated extracted by suitable coolers. A large proportion of the recoverable petrol then condenses, but it is found that the remaining gas still contains sufficient petrol to make further treatment in an absorption plant profitable.

In the absorption plant the gas is passed through towers and is brought into intimate contact with an absorbent, which generally consists of the fraction of the crude after the kerosene has been extracted from it. The recovery of the absorbed petrol from the absorbent is afterwards effected by distillation.

Petrol recovered from natural gas is particularly volatile, and is valuable for grading up the heavier fractions produced by other methods. As already pointed out, extension of the distillation range in straight refining is largely dependent upon the quantity of low boiling-point fractions available for providing the essential degree of volatility, so that natural-gas petrol augments supplies by considerably more than its own volume alone.

Conclusions.—It is evident from the foregoing that it would not be reasonable to expect any improvement in the fuel position if the automobile and petroleum industries continue their relative rates of development.

The most practicable solution appears to be in the hands of the engineer. Present-day engines are wasteful, working as they do under "throttled" conditions, making for high fuel consumption per power unit developed. The production of engines of smaller capacity to work at the most economical load factor at all times is dependent to a great extent upon the evolution of the perfect infinitely variable gear—upon which much thought and labour have already been expended. In this connection it is interesting to note the present trend of development, tending toward smaller and more efficient engines for all types of automobiles. Although material in effecting some reduction in the consumption of each individual power unit, this trend of development does not greatly assist the petroleum technologist in lessening the demand for more, and yet more, fuel of the most volatile character. It is necessary to look further ahead to see in what direction improvement of the automobile engine must take place in order to correlate the work of the automobile engineer and the petroleum technologist.

It has been shown that the quantity of fuel produced can be increased considerably by decreasing the specification with regard to volatility. If, then, an engine is available capable of burning heavy fuels satisfactorily, the problem resolves itself into one of readjustment of refinery programmes.

The vaporiser as a means for utilising only a moderately heavy fuel is, at its best, but a compromise, although it is suggested that the evolution of the efficient oil-gas producer, in a compact form, will solve the problem in the simplest way possible.

The application of a principle new to the automobile engine (viz., injection of the fuel by mechanical means direct into the combustion space at the commencement of the combustion period)

appears to offer the most scientific solution to the problem of utilisation of heavier fuels. In such engines ignition is obtained by the temperature of compression, together with some localised heat in the zone into which the fuel is injected. Higher thermal efficiencies will also be obtained due to the increased compression ratios employed.

An abstract follows of the paper read before the London Branch of the Students' Section on May 19th, 1925.

Emulsions.

By J. O. Tanner, B.A. (Cantab.).

There are three types of emulsifiers:

1. The emulsifying agent is a charge on the dispersed phase. The origin of this electrical charge is obscure, it may be due to ion absorption, or, as Ellis ascribes it, to a difference in dielectric constants, according to the rule of Cohen, that a substance of high dielectric constant is positive to one of a lower dielectric constant when one is dispersed in the other.

2. The emulsifying agent is a soluble colloid when it may be (*a*) soluble in water (oil in water), or (*b*) Soluble in oil (water in oil). Good emulsifiers of the former are sodium and potassium soaps, egg albumen, gelatine, glue, gum arabic, milk; and of the latter calcium, aluminium, magnesium oleates, *asphalts*.

3. The emulsifying agent is an insoluble or very slightly soluble substance. These may be divided into:—(*a*) Those which are wetted more easily by water than oil (water in oil) and (*b*) those more easily wetted by oil than water (oil in water). Good emulsifiers of the former are basic copper sulphate, basic ferrous sulphate, basic nickel sulphate, silica, and of the latter lamp black.

All crude petroleum emulsions are of the water in oil type, the emulsifying agent being some oil soluble colloid, or some finely divided solid that is more readily wet by oil than water. Crude petroleum contains heavy hydrocarbons such as asphalt, asphaltenes, etc., which are probably in colloidal solution and could reasonably be expected to act as emulsifying agents. Sherrick suggests the importance of these asphalt-like bodies in the formation of petroleum emulsions, but since not all asphalt base oils emulsify easily, he thinks that these colloidal substances are not alone effective as emulsifying agents, but must first be adsorbed upon hydrated

earthy material, which is thus changed from a water to oil soluble colloid.

This does not seem probable, because the conditions cited by him, as favourable for the formation of such a colloid, are not likely to have been of wide occurrence, and because many emulsions contain little or no earthy matter.

Furthermore, such an assumption is not necessary, the nature of the solution of the asphalt-like bodies in the crude oil probably depends upon the ratio of light fractions to heavy, and consequently the tendency to emulsify should be expected to vary as the dispersion approaches that of true solution, and the tendency to emulsify should be expected to decrease.

In every case it has been found that dilution with benzine has made the emulsion more difficult to break. This indicates that the degree of dispersion of the asphalt-like bodies is more favourable for emulsification in light fractions than in heavy.

Crude petroleum is said to contain traces of saponifiable organic acids. If this is a fact, it is reasonable to expect oil soluble soaps which might act as emulsifying agents, but the amount of these would be so small that, if present at all, they may be neglected.

Turning to the breaking of emulsions we find that in general de-emulsification can be accomplished by:—Addition of excess of dispersed phase; addition of a liquid in which the liquid phase is soluble; destruction of the emulsifying agent or its conversion, and transportation out of the field of action; filtration; heating; "topping"; freezing; centrifuging, or electrical dehydration.

There are two antagonistic forces at the interface between the phases of an emulsion, namely: (*a*) the surface tension which tends to cause coalescence; (*b*) the coherence of the film of emulsifying agent which tends to resist coalescence, and the stability of an emulsion depends upon the relative magnitudes of these opposing forces. If the coherence of the film of emulsifying agent is so great that the surface tension is unable to rupture it, the emulsion is permanent.

Thus it is evident that there are two general methods by which the stability of an emulsion may be decreased: first by an attack upon the emulsifying agent, and secondly by increasing the surface tension at the interface.

Chemically the attack upon the emulsifying agent may be made by destroying it or by converting it into an ineffective form.

The ideal method, of course, is to destroy it and thus give surface tension, however small, an unrestricted opportunity to cause coalescence, but this is often impossible or unpracticable.

To convert the emulsifying agent into an ineffective form a substance may be added that dissolves it, and thus removes it

from the interface, or one that flocculates it to such an extent that a coherent film is no longer formed, or one that tends to form the reverse type of emulsion, a "counter colloid."

On the producing side of the question it is seen that the maximum efficiency of a pumping well which is producing both water and oil is obtained when the fluid is kept above the perforated tubing and below the point where the accumulated head would stop inflow.

A small, steady amount of emulsified material is probably due to bad valves and cups in the pumping appliance.

Percentages of emulsion increase as the column of fluid around the tubing is exhausted, for such a condition allows air to enter the working barrel, or a break to occur in the column of fluid, since either air, or gas, or a void in the continuity of the fluid accelerates the formation of an emulsion.

STUDENTS' SECTION.—BIRMINGHAM BRANCH.

An abstract of the paper read at the meeting of the Birmingham Branch of the Students' Section, held on March 17th, 1925, follows:—

The Restoration of Production in Abandoned Fields.

By G. C. H. Dunsterville.

Of the oil retained in a sand after a well has reached economic exhaustion by ordinary production methods, part is retained so firmly by capillarity and adhesion that its removal is possible only by the use of heat. In a laboratory test in which oil was drained from a sand at 70° C. this amount varied from 15 per cent. of the sand capacity with a light oil in a coarse sand to over 50 per cent. with a heavy oil in a fine sand. How firmly this oil is retained was shown by letting fresh water flow through the drained sands, when in only one case was there even a trace of oil to be found in the water that had passed through. This quantity retained seems to mark the limits of recovery of any of the methods discussed in this paper, but between this minimum and the amount usually left in the sand there is a great quantity of oil that can be recovered.

Other experiments were conducted to test the efficiency of oil recovery by water displacement by allowing water to rise through the tubes from the bottom to the top under varying conditions of sand, oil and pressure. The oil so displaced was accompanied by so much water that its recovery would not be feasible in the field, and when the conditions were made to resemble field conditions as nearly as possible, the portion of oil ultimately retained in the sand was found to be greater. This was particularly true when the sand was first partly drained, the water showing a tendency to by-pass and trap the oil.

By forcing compressed air or gas through the tubes, greater recoveries were obtained than by water displacement or natural drainage. This now leads us to the consideration of the various means by which attempts have been made to get a further production of oil from wells which have reached their drainage exhaustion point.

One of the first systems to make an appearance was that of vacuum or gas pumping, and there are records of its use in Pennsylvania in 1869. It is now extensively used on the Mid-Continent field of America. This system consists simply of placing wells under a partial vacuum by the use of gas pumps, and the effect of this is twofold; the yield of oil is increased and the richness of the gas is also increased.

Gas pumps are usually placed on wells when the flow production has dropped to a very low figure, and the gas pressure has fallen very nearly to atmospheric. Thus the gas pump will effect a further reduction of only 15 or 20 lb. at the most. The effectiveness of the pump will rest on the gases released in the sand by the drop in pressure, and when this is exhausted the pump has reached its limit of usefulness so far as increased production is concerned. Though the original flow of oil may be even doubled or trebled by the use of vacuum pumps, this production will seldom last long, and in a very few years will drop to its former economic limit.

Gas pumping considerably increases the cost of oil production, and were it not for the benefit derived from the enriched gas taken off, it is not often that this extra cost would be compensated for by extra profit from the oil.

The wide use of gas pumping is due to two causes. One is the increase of good casing-head gas, and the other is the close grouping of small companies on an oilfield. By using vacuum, one company finds that it can increase its production at the expense of another. The latter then has to adopt the system in self-defence.

Perhaps the effect of gas pumping on neighbouring *oil* production has been over-estimated, but when the *gas* is the consideration the effect is of undoubted importance.

Thus we may summarise the effects of gas pumping by saying that though it increases production of oil, it also increases production costs, and the total production is only slightly more than that obtained by ordinary pumping methods.

The Compressed Air Process, sometimes known as the Smith Dunn or Marietta process, was first started in 1911, and has made rapid headway, and is now used on many fields throughout the world.

The essential principle of this system is to replace the escaped natural gas with compressed air. The air is forced into the sand through various wells on the property, which are called air-wells, and the oil is collected from the other wells in the normal way.

Any gas which does not react with the oil may be used, and the obvious ones are either air or casing-head gas. On the old, nearly exhausted properties where the system is generally used, the natural gas available is very scarce and consequently air is used.

The essential equipment of an air well consists of a 2 in. pipe which extends from the casing-head to the top of the oil sand, and is very firmly packed just above the top of the sand. If the original casing extends right to the oil sand it may be used instead of the piping, the essential point being the efficiency of the packer. This is to prevent the escape of air to other formations in the overlying strata. On the subject of suitable packers it has been found that the ordinary rubber packer is not sufficiently strong to withstand the high pressure, and in shallow wells it is recommended to use cement. It is not often necessary to shoot the well at the start, but it is always advisable to clean the well before putting in the compressed air system.

By placing a reducing valve on the gas-gathering line from the casing head of a pumping well a back-pressure can be maintained whose value lies in the fact that under the higher average pressure between the air well and the oil well, more air will go into solution in the oil and energy will thus be conserved. The air will also force its way into the tighter parts of the oil sand and move oil which under other conditions would remain untouched.

We now come to the question of the proportion of air wells to oil wells. This will naturally be dependent on the local conditions of the property and also on the maintenance or otherwise of back-pressure. When there is no back-pressure being used, experience has shown that as a general rule the best results are obtained by distributing a large number of air wells as uniformly as possible among the oil wells. When using back-pressure it is found that fewer air wells are necessary, and that these wells should be chosen not so much for their position as their air-taking capacity. The actual placing of the wells will naturally have to depend on the

judgment and experience of the operator. Where back-pressure is not being used, it is advisable to install as many as two air wells to every five producing wells.

The average pressure used for air wells is 115 lb., varying from 40 to 320 lb., while the average volume of air is 10,000 cu. ft. per well supplied per day. Thus if the proportion of air wells is one to three, 30,000 cu. ft. of air should be pumped in per day, and as the oil is removed from the sand greater volumes will become necessary.

The third main system for the increase of oil recovery is the Water Displacement method, and there is perhaps more disagreement on the subject of its efficiency than upon any other process.

The general recognition of the fact that the entrance of water into an oil sand may lead to trouble is shown by the stringent laws passed in nearly all oil-producing countries to prevent such an occurrence, but at the same time the fact that water would displace oil from a sand, and that the production of a well could be improved by a process of water flooding for a time at least, led to much speculation on the subject.

However, as it is acknowledged by all that, whether a water flood increases production or kills it, once tried, no other system can afterwards be used, it is best to consider very carefully indeed all the conditions of the case before deciding to employ it.

The theory and principles of flooding must first be considered. Flooding is based on the theory that if a liquid can, by replacing oil in the pores of a sand, overcome the capillarity, adhesion and frictional resistance which tend to keep oil in the sand, then the oil will be concentrated in front of the flow of liquid and forced into pumping wells at a greater rate than before. Water, as is well known, will effect this, and the benefits derived from such an action will depend largely on the conditions in the field and the extent to which the operator is aware of the movements of the water.

The idea underlying the water flood system is very simple indeed. Imagine a field in which the gas pressure has been exhausted to such an extent as to render the oil production very poor.

By letting water into certain wells it is obviously possible to concentrate the oil round the other wells and thus increase their production. The production of oil replaced by the water is by no means 100 per cent., for, as has been mentioned earlier on in this paper, water may be passed through a drained sand without further removal of the oil. But with a field on which it was found that flooding could be made to take place steadily, the increase of production might quite conceivably be sufficient to warrant the employment of the system. Such a field is the Bradford field in Pennsylvania, where the system has worked perfectly, but in the

majority of cases the operation is by no means an easy affair owing to the extremely erratic behaviour of the water.

Naturally, with a level sand with uniform conditions throughout, water entering by a well would spread out in an ever widening circle, whose area would increase at a uniform rate. That is to say, the rate at which the margin of the flood advanced would get slower and slower as time went on, the area of the circle being proportional to the square of the radius. Thus a flood advancing 100 ft. in one year would advance only 41½ ft. in the second year, 32 the third and so on. But in practice, due to the presence of many factors, this rate decreases very much more quickly. Amongst these factors are the increase of resistance with the distance traversed, the resistance due to the concentration of the oil in front of the water flow, and the clogging of the sand pores with silt and waxy materials.

REVIEWS.

"Shale Oil." By Ralph H. McKee, Ph.D., LL.D., and others.

This is a most interesting and useful little book. It is a compilation by eight authors, including Mr. McKee, who edits the volume, of all that is known about oil-shale and the incipient oil-shale industry in the United States of America.

There are chapters on the origin of oil-shale, the geology and distribution of oil-shales, the refining of shale oil, etc., and several general chapters dealing with various aspects of a shale oil industry. There is also a chapter giving brief accounts of all, or nearly all, the various retorting plants that have been installed in the United States, while the book finishes with a very complete bibliography, 129 pages long, in the form of very brief abstract of articles and papers from all over the world dealing with oil-shale and shale oil. Some of these abstracts, it must be admitted, are very badly done, and certainly do not represent fairly the views of the writers: this has no doubt arisen from the attempt to condense intricate scientific theses into a few lines. A plain bibliography without abstracts would have been better.

There are many matters of interest to technologists in the book: for instance, the chapter on nitrogen constituents of shale oil, and graphs showing exothermic stages at the higher temperatures reached in retorting a shale; but perhaps the most significant part of the book deals with the possibilities of, and the prospects before, an oil-shale industry in America. It is evident that technologists view with alarm the inevitable shortage of free petroleum that is due to arrive as the oil fields become depleted, and are already preparing to meet the difficulties of keeping the country supplied with liquid fuel. It is recognised that though there are several sources from which motor fuel may be obtained, oil-shale is by far the most important. Chapter IX., on the Basic Factors of the Shale Oil Industry is admirable, and it is made quite clear that a broad view is being taken of the problems of the future, and that a shale industry must be built up steadily and carefully if it is to have any hope of becoming sufficiently large, to be of importance by the time supplies of free petroleum have sunk too far below the demand.

Those parts of the book dealing with research, both geological and chemical, do not contain much that can be called new: it is evident that in such matters America is still some years in arrear. It is a pity that the liaison between scientists in this country and America is still imperfect, and therefore work and research that has been done over and over again has still to be repeated for similar results. It is not the fault of the various authors that they have in some cases given publicity to statements published in this country which are entirely inaccurate. To take a single instance, it is stated that the Norfolk oil-shales contain a band of torbanite which yields from 85 to 95 gallons of oil per ton. Torbanite is admitted to be a different deposit from oil-shale, but there is evidently still some confusion of ideas on this point, as torbanite seams are in several instances recorded as shale, while the very startling statement is actually made that torbanite and oil shale pass into each other—presumably in the same manner that chalk passes into cheese. These, however, are merely minor defects in a very

interesting book, and are only examples of the difficulty that American authors experience in getting really reliable information about European geology.

There is a serious misprint on page 49, which has the effect of placing the Albert shales of New Brunswick (with their Lower Carboniferous or Devonian fish fauna) in the Precambrian.

E. H. C. C.

BLACKS AND PITCHES. By H. M. Langton, M.A., B.Sc., A.I.C. Pp. 179. Ernest Benn, Ltd.

The Oil and Colour Industry has long been noteworthy for its progressive outlook and for the sound scientific methods which characterise its development. In no way is this better exemplified than in the publication of the series of "Oil and Colour Chemistry Monographs," of which Mr. Langton's book is a meritorious example. Concisely written by one obviously in close touch with his subject it is of the size and scope to which the term monograph rightly belongs. Moreover, it fills a distinct gap in the compiled knowledge of an industrial subject little known to the average technologist.

In his preface Mr. Langton explains on the grounds of industrial exigence and common origin the inclusion of two "such apparently dissimilar and unrelated classes of substances as Blacks and Pitches." Such an apologia would have been unnecessary had account been taken of the recent work of Nellensteyn, who has shown that the asphalts are best to be regarded as organosols of colloidal carbon dispersed in the colourless asphaltenes. This view very naturally and simply places the blacks and the pitches under one heading.

With the exception of the synthetic dyestuff blacks and a few metallic oxides, all the industrial black pigments have carbon as their essential basis. The manufacture and application of carbon black (natural gas black) and lamp black are therefore treated extensively, though the use in the rubber industry of the former, and of the allied thermatomic carbon produced by the heat decomposition of hydrocarbon gases and vapours, might with advantage have been amplified for the benefit of those to whom modern developments on the subject of fillings for rubber are unknown.

The sections devoted to the pitches and bituminous materials form two-thirds of the book, and here, particularly, Mr. Langton has carried out his difficult task with marked success. The involved nomenclature and the masses of empirical data are handled with much skill and the reader gets an oversight of the subject difficult to obtain elsewhere.

The last chapter, on bituminous paving materials, is of particular interest to those engaged in the petroleum industry. It is to be hoped that in future editions of the monograph Mr. Langton will develop this section and describe more fully the important work which is being done on surface phenomena and colloidal solution in their relationship to this important branch of petroleum technology.

S. J. M. A.

BOOKS RECEIVED.

THE HEATING OF ROOMS. Margaret Fishenden, assisted by R. E. Willgress. *Fuel Research Board Technical Paper No.* 12. H.M. Stat. Office. 1s. net.

Dr. Fishenden has carried out investigations for the Department of Scientific and Industrial Research on the relative costs of keeping a room comfortably warm to its occupants by various methods of heating in different circumstances.

THE ENRICHMENT OF COAL GAS BY THE INJECTION OF OIL INTO THE RETORTS DURING CARBONISATION. *Fuel Research Board Technical Paper No.* 14. H.M. Stat. Office. 1s. 9d. net.

Gas oil introduced into the retort by a water-cooled tube to prevent cracking of the oil resulted in an increase of both gas calorific value and of gaseous therms.

REPORT OF TEST BY THE DIRECTOR OF FUEL RESEARCH ON THE CARBONISATION PLANT OF MIDLAND COAL PRODUCTS, LTD., NETHERFIELD, NOTTINGHAM. *Dept. of Sci. and Indus. Research.* H.M. Stat. Office. 9d. net.

Low grade slack coal, briquetted before carbonisation, was used. The retort is heated internally, resulting in the production of less solid fuel but a large quantity of gas of low calorific value (about 200 B.Th.U. per cu. ft.). The coke contained less volatile matter than usually found in "low temperature" coke but is very suitable for use in stoves.